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Performance of Activated Sludge-Powdered Activated Carbon-Wet Air Regeneration Systems

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16. ABSTRACT

The investigation summarized in this report was undertaken to evaluate the performance of powdered activated carbon (PAC) technology used in conjuntion with wet air regeneration (WAR) at municipal wastewater treatment plants. Excessive ash concentrations accumulated in the mixed liquor suspended solids (MLSS) at all facilities that relied on the WAR unit blowdown for ash control. A variety of ash control methods have been implemented and are documented. The nitric acid test for PAC was shown to substantially overestimate PAC concentrations. PAC losses across WAR or the desirability and economics of recovering the volatile suspended solids (VSS) exiting the WAR reactor could not be quantified. Other areas covered in the report include adsorptive capacity of the recycled material, tertiary filter performance, metals accumulation, oxygen transfer, operation and maintenance concerns and economic considerations. The report includes Appendices submitted by the system manufacturer that dispute many of the report conclusions and provide alternative explanations for some of the data obtained.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

The evaluation summarized in this report was undertaken by the USEPA to document the performance of municipal wastewater treatment facilities using powdered activated carbon (PAC) addition to activated sludge combined with wet air regeneration (WAR) of the waste PAC/activated sludge stream.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

DISCLAIMER

This material has been funded wholly or in part by the United States Environmental Protection Agency under contract 68-03-3429 to James M. Montgomery Consulting Engineers, Inc. It has been subject to the Agency's review and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

This document presents the results of an evaluation of full scale activated sludge systems utilizing powdered activated carbon (PAC) addition with wet air regeneration (WAR). The evaluation was undertaken by the U.S. EPA to document the performance of the PAC/WAR technology at municipal plants so that future facilities considering this process would have the benefit of operating experience gained to date. Additional goals were to determine the efficacy and cost effectiveness of changes proposed to bring several of the plants into compliance with their discharge permits.

This report was submitted if fulfillment of contract 68-03-3429 by James M. Montgomery Consulting Engineers, Inc. under the sponsorship of the U. S. Environmental Protection Agency. This study was initiated in 1987 and reflects information available on or before August, 1988. The report was completed in October, 1989.

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ACKNOWLEDGEMENT

The authors wish to express their appreciation to the owners and operators of the PAC/WAR wastewater treatment facilities that were included as part of this study. These include: Vernon, CT; Mount Holly, NJ; East and South Burlington, NC; Kalamazoo, MI; Bedford Heights, Medina County and North Olmsted, OH; and El Paso, TX.

SECTION 1

INTRODUCTION

Addition of powdered activated carbon (PAC) to activated sludge systems is a proven technology for wastewater treatment (1, 2, 3, 4). The use of wet air oxidation for the treatment of non-PAC sludges such as primary and secondary sludges is also an established technology (5, 6, 7, 8). Eleven municipal facilities in the U.S. have been built using these combined technologies, with the wet air oxidation process, which is commonly called wet air regeneration (WAR), used for oxidation of excess biological solids and regeneration of spent PAC.

The Clean Water Act Amendments of 1977 and the Municipal Wastewater Construction Grant Amendments of 1981 include provisions which encourage the use of innovative and alternative technologies. Innovative technologies are eligible for increased Federal funding and failed innovative technologies may be eligible for a 100% modification and replacement (M/R) grant. Post construction evaluations are conducted to identify technologies implemented in the field that are beneficial and to establish the causes for alleged failures of innovative technologies.

Nearly all municipal systems designed for PAC addition in the U. S. have included WAR. A majority of these systems received Federal funding under the innovative technology program. Subsequent contact with these facilities revealed that excessive mixed liquor solids accumulation owing to ash buildup has been a common problem. Solutions proposed to correct this problem have resulted in several 100% M/R grant requests. Other problems reported at one or more facilities have included ash related effluent quality violations and excessive metals accumulations, inability to treat sustained recycle loadings from WAR, inadequate oxygen transfer to aeration basins, heavy scum accumulation on secondary clarifiers, heat exchanger fouling and failures, and high operating and maintenance costs.

The evaluation summarized in this report was undertaken by the U.S. EPA to document the performance of the PAC/WAR technology at municipal plants so that future facilities considering this process would have the benefit of operating experience gained to date. Additional goals were to determine the efficacy and cost effectiveness of changes proposed to bring several of the plants into compliance with their discharge permits.

SECTION 2

SUMMARY

This investigation was directed solely to municipal facilities which used PAC addition in conjunction with WAR and returned the WAR discharge to the plant's aeration basin(s). The following summary comments pertain to PAC/WAR facilities only, and would not be applicable to facilities using PAC on a single-pass basis. The information on plant operation and performance contained in this report reflects data available on or before August, 1988.

The nitric acid digestion procedure used for process control and WAR performance evaluation substantially overestimates PAC concentrations.

Claims that PAC losses through WAR are 5 percent or less are based on material balance approaches which make selected use of the nitric acid digestion technique. The losses measured at E. Burlington NC, Kalamazoo MI, and Mt. Holly NJ with the nitric acid digestion technique averaged from 31 to 41 percent per cycle, but this is really only a qualitative estimate of the actual loss. Recktenwalt's results (9) in conjunction with other information suggest that an average loss of 15 to 20 percent per cycle is an informed estimate of the true loss.

As a consequence of the inability to measure the PAC fraction of the VSS exiting a WAR unit, the economics or desirability of recovering this material cannot be accurately quantified. Economic evaluations that rely on the nitric acid digestion technique to measure the PAC fraction overestimate the amount and value of PAC recovered.

Previous researchers (9) have shown that PAC subjected to multiple regenerations loses adsorptive capacity for some compounds, but not for others. The value of the regenerated material is dependent upon the compounds which it is designed to remove.

Ash accumulated in all PAC/WAR systems which relied on WAR unit blowdown for removal of a concentrated ash stream. Various methods were devised by the system manufacturer and/or the plant owners to control ash accumulation. All facilities have modified or are in the process of modifying the design and/or operation of

their facilities to limit ash buildup. Several methods including using non-activated carbon (NAC) with no regeneration, discontinuing PAC addition, wasting a fraction of mixed liquor and wasting a fraction of WAR reactor effluent have been successfully implemented to control ash buildup. Facilities that have controlled ash buildup have been able to maintain acceptable effluent quality.

Nondegradable VSS accumulation is probably common to all facilities which operate PAC/WAR systems.

Loadings attributed to the WAR return stream are significant in terms of ash, BOD_5 and NH3-N. Total phosphorus can also be quite high, especially where mineral addition is used for phosphorus removal. The high phosphorus concentrations recycled through PAC/WAR systems must be considered by plants with effluent phosphorus limits.

Bedford Heights, OH experienced operating and effluent quality problems attributed to accumulation of heavy metals in the MLSS. Vernon, CT also noted high metals concentrations but EP Toxicity Extraction Analyses indicated no appreciable leaching.

Special considerations include the degree of skill required to operate and maintain high pressure equipment. Pressure valves still experience a limited service life and are the object of continuing design evaluation. Scale buildup, compressors and high pressure feed pumps require skilled and regular attention.

There was no evidence that the alpha values at El Paso, TX, which varied from 0.24 to 0.65, were any higher than would be expected with conventional activated sludge systems.

Average 1986 O&M costs for three facilities were $21.86, $27.68 and $42.00 per 1,000 gallons of material processed through the WAR reactor.

Zimpro, Inc. does not concur with all conclusions in this report and their comments are included in Appendices A and B.

SECTION 3

RECOMMENDATIONS

Ash buildup was observed at all PAC/WAR facilities operated according to the original design intent. A variety of methods available for ash control are documented in this report. Selection of the most cost effective ash control method depends on several factors including the value of the material (PAC plus other VSS) exiting the WAR reactor. It's value, in turn, is unique to each plant and depends on the material(s) the recycled WAR effluent VSS are designed to adsorb, the ability of the recycled VSS to actually adsorb the material(s), and any other benefits which are attributed to these returned VSS. The nitric acid test procedure used by operating facilities to measure PAC concentrations will not quantify the PAC concentration in the WAR effluent stream.

Any facility which chooses to maximize the recovery of the VSS available from the WAR reactor (such as by use of a differential sedimentation and elutriation system) must quantify the benefits of the recovered material vs. the increased cost for its recovery. Equating the nitric acid test value determined for PAC mass in this stream to an equal economic value for the same mass of virgin carbon as the sole measure of determining the economic benefits of the recycled material is not appropriate.

SECTION 4

TECHNOLOGY DESCRIPTION

Figure 1 illustrates a flow diagram for a typical municipal system incorporating the PAC/WAR technology. Virgin PAC is added to the activated sludge system influent as a make-up dosage. Recommended MLSS concentrations (3) range from 15,000 to 20,000 mg/L of which 2,000 to 6,000 mg/l is PAC. A slip stream from the secondary clarifier underflow, which is composed of an activated sludge-PAC mixture, is thickened to 6 to 7 percent solids prior to being pumped to WAR. Effluent filters, at one time considered optional (10), were installed in nearly all of the municipal systems and are now considered an integral part of the process.

Figure 2 illustrates the major components and functions of the WAR system. The purposes of the WAR system are to destroy excess biomass, regenerate PAC and provide a means of controlling ash build-up. High pressure feed pumps are used to pump the activated sludge-PAC mixture to the WAR system and to sustain an operating pressure of approximately 800 psi. Air is injected into the sludge/PAC stream by means of multiple stage, high pressure compressors to oxidize organic materials present in the sludge mixture. Two stages of heat exchangers are included for the mutual functions of reducing the temperature of the treated material and increasing the temperature of the incoming material. The air/sludge/PAC mixture reacts in a vessel (reactor) for a period of 25 to 50 minutes prior to being discharged through the heat exchangers. Steam boilers are used at the beginning of each operating cycle to raise the system temperature. The oxidation reaction generally provides most of the heat required to sustain the reaction temperature between 230 to 245°C.

Material exiting the WAR system consists of a mixture of PAC, other volatile suspended solids, non-volatile suspended solids (NVSS), and a large component of soluble organics (which are formed in the process). This stream is returned to the aeration basin along with the small makeup PAC dose.

Ash blowdown quantities, when treating primary clarified domestic wastewater, were expected to vary from 100 to 200 lb/MG of wastewater flow (3). In accordance with the claims for the process (11), the reactor blowdown stream shown in Figure 2 was the only means of controlling ash in the original design approach.

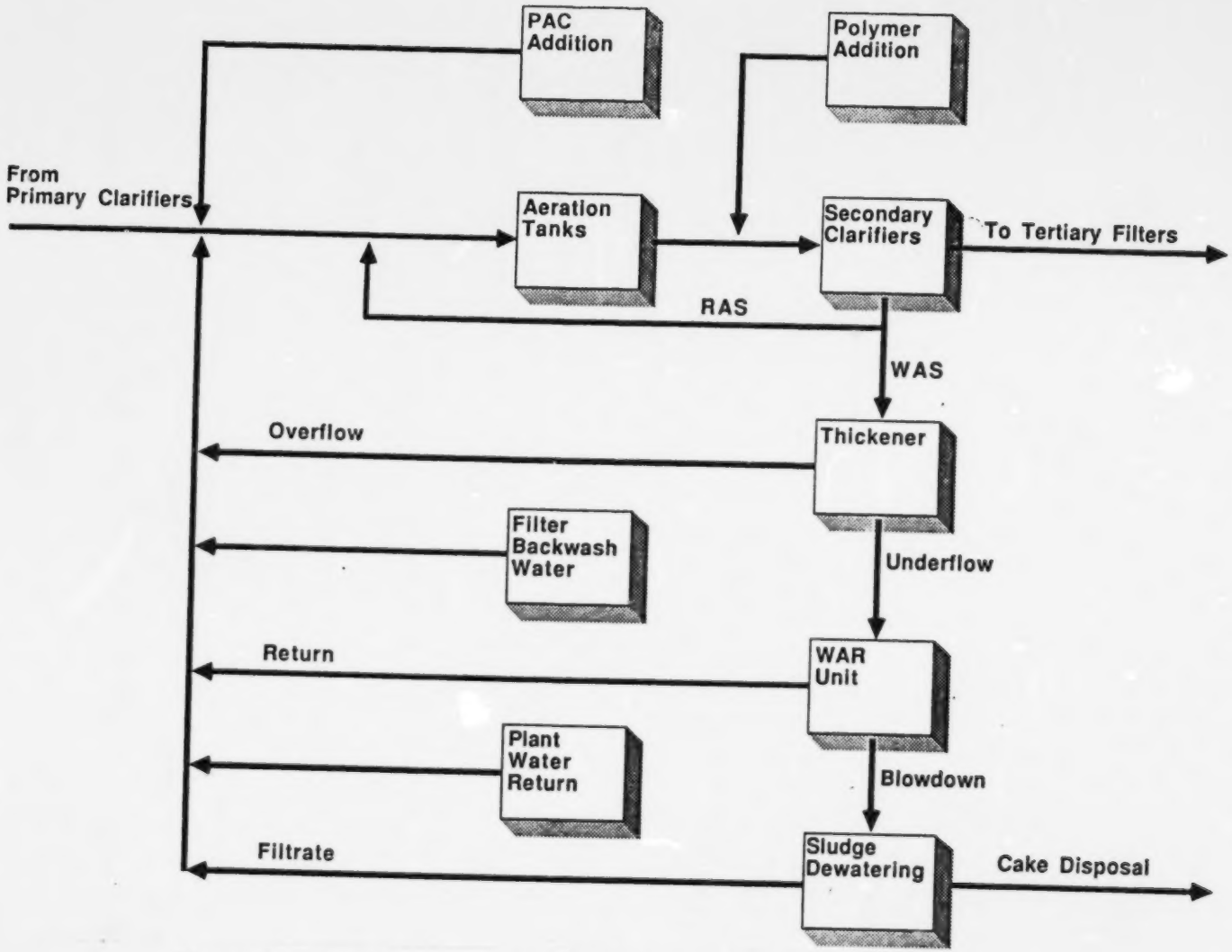


Figure 1. Flow Diagram of Typical System with PAC/WAR

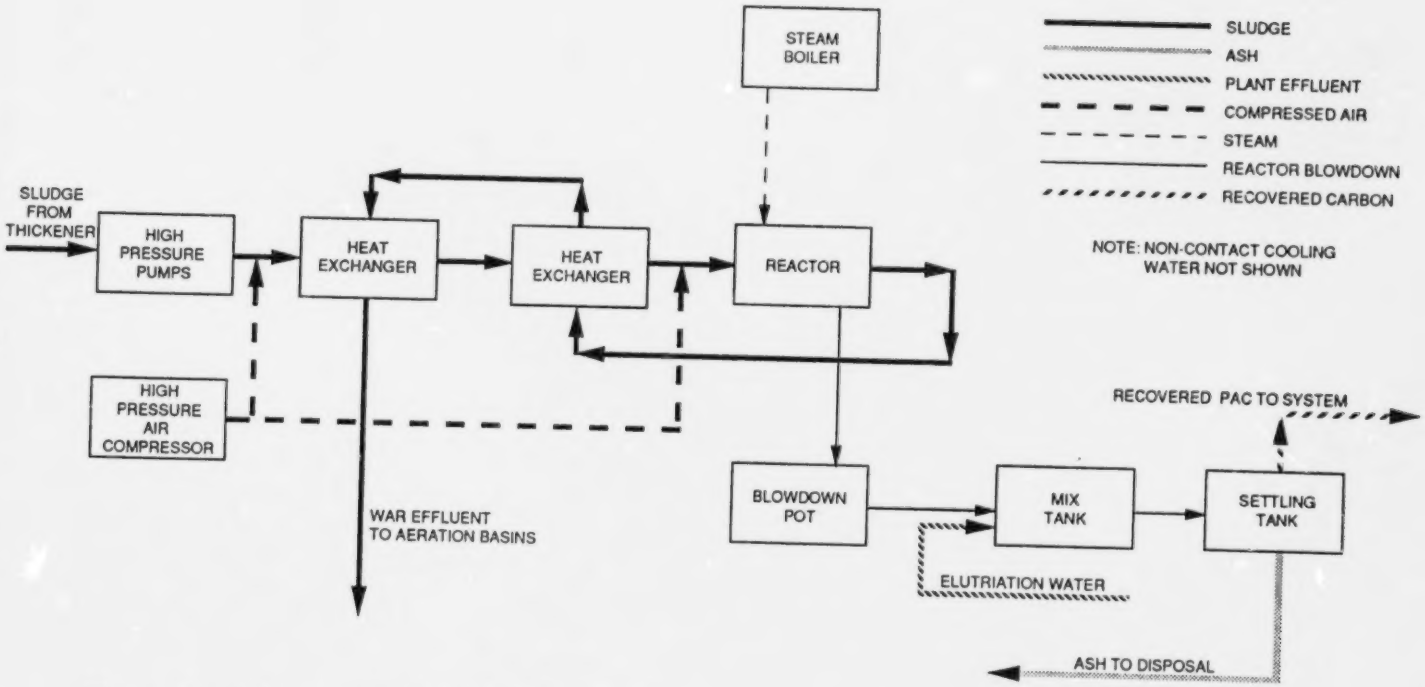


Figure 2. Major Components of a WAR System

This stream was to be mixed with plant effluent and a return stream from a parallel plate settler underflow before flowing to the settler for separation of the PAC and ash materials. The settler overflow, containing recovered PAC, was to be returned to the process. A portion of the settler underflow, containing settled ash, was to be wasted.

SECTION 5

STUDY PROCEDURES

Prior to initiating this investigation, the EPA conducted a peer review meeting with representatives of the EPA, Zimpro Corporation and a 3-member peer review panel (1 consulting engineer, 1 university professor and 1 PAC/WAR plant superintendent) to identify issues deemed to be important and the best methods consistent with the available budget to pursue this study. The peer review panel prepared a summary report outlining areas of information deficiency. This report was used by EPA personnel to determine the initial project scope and to specify the procedures to initiate the study which began in 1987.

Initially, discussions were held with operating facilities, U.S. EPA regional offices and the process manufacturer to gather background information on the municipal PAC/WAR treatment plants. Typical process data were collected from the various facilities and reviewed. Site visits to five facilities were made to review the intended vs. actual operation, types of plant records maintained and analyses performed, and a thorough plant inspection to document locations of sampling points and sidestreams. Following a preliminary analysis of the data and assessment of the PAC/WAR process, a review meeting was held (12/87) with Zimpro, EPA personnel and the contractor team to assess and discuss the preliminary findings. Information and discussions from this meeting were used by the EPA to determine steps needed to complete the evaluation. Subsequent visits were made to two more facilities to gather additional data. Following plant visits, supplemental conversations were held with the various operating plants to confirm information or secure missing data. This information was analyzed along with other published data to complete the technology evaluation.

A summary of the results was presented and discussed during a final meeting (8/88) with several EPA personnel, Zimpro personnel and the contractor team. These results were documented in a technical paper, subjected to EPA peer review, and presented at a meeting of the Water Pollution Control Federation in Dallas, Texas (12).

Discussions during the final review meeting and subsequent communications (Appendix A) concerning the Dallas paper (12) have clearly indicated a difference of opinion as to the appropriate

interpretation of much of the data which have been assembled. Upon review of these concerns, the authors of this report (Deeny, Heidman and Condren) have found no technical basis to change the conclusions presented in the Dallas paper. For this reason, Zimpro, Inc. has been afforded the opportunity to provide an appendix to this final report (Appendix B) so that their viewpoints will also be available to the reader.

SECTION 6

RESULTS

PLANT SUMMARY

A summary of the municipal PAC/WAR facilities reviewed is presented in Table 1. Color reduction, nitrification, limited space availability and toxics removal were the predominant factors given for this technology's selection. Effluent permit limits range from typical 30/30 mg/L for BOD5 and TSS (with and without nitrification) to summer limits of 7/20/2/1 mg/L for BOD5/TSS/NH3-N/T-P at Kalamazoo. The current status of municipal facilities indicates that all have, in some way, modified the original design and/or operation of their systems.

ASH ACCUMULATION AND CONTROL

Literature Survey

Ash accumulation was observed by Knopp and Gitchel (13) in a two-stage physical-chemical PAC system treating primary effluent followed by a sand filter in studies at the Village of Rothschild, Wisconsin. Data were collected over a 28-day period with portions of the spent PAC regenerated on a batch basis. Ash content of the virgin carbon was 5.4 percent and this increased to 14 percent within 25 days. The change in ash content was gradual with no evidence of reaching an equilibrium value. Table 2 summarizes the ratio of regenerated/virgin components after 23 operations of the wet air regeneration system, representing approximately 6.4 regenerations of the carbon charge.

Sodium and potassium were present in relatively high concentrations in the vigin Nuchar A carbon and it was felt they would not be precipitated from the wastewater. The concentration of these elements should be more indicative of attack on the original PAC. If the PAC structure was uniformly attacked, the ratio for the Na and K would imply a removal of 72 to 88% of the original material. However, they hypothesized that the attack was more selective such as removal of sulfonates from the matrix.

Results from a combined PAC/activated sludge system with WAR obtained during a 51-day period of steady state operating conditions during the summer of 1972 at the Rothschild, Wisconsin plant were summarized by Burant and Vollstedt (14). The primary

Table 1. Summary Of Municipal PAC/WAR Facilities Reviewed

Facility	Flow, mgd Current/ Design	PAC/WAR Status[1]	Reason For PAC[2]	Permit Limits BOD5, mg/l	TSS, mg/l	NH3-N, mg/l
Vernon, CT	4.2/6.5	MA	C	10	20	-
Mt. Holly, NJ	2.4/5.0	MA	C,S	30	30	20
E. Burlington, NC	7.0/12.0	MA	C,N,T	12-24	30	4.0-8.0
S. Burlington, NC	6.8/9.5	AS	C,N,T	12-24	30	4.0-8.0
Kalamazoo, MI	25/54	MA	C,N,T	7-30	20-30	2.0-10.0
Bedford Hts., OH	3.4/3.5	NAC	N,S	10	12	5.1
Medina Co., OH	7/10	MA	N	10	12	1.5-8.0
N. Olmsted[3], OH	6/7	AS	N,S	30	30	2.3-6.9
Sauget, IL	16/27	AS	T	20	25	-
El Paso, TX	4.5/10	MA	N,O	SD[4]	SD	SD

(1) MA = Modified operation and/or design for ash control.
AS = Converted to conventional activated sludge.
NAC = Converted to the use of non-activated carbon without regeneration.

(2) C=Color Removal, S=Space, N=Nitrification, T=Toxics, O=Organics

(3) Plan to convert to NAC without regeneration.

(4) SD=Secondary Drinking Water Standards

Table 2. Changes in Ash and Carbon Composition with WAR (13)

Component	Regenerated/Virgin Ratio
CaO	3.26
MgO	2.19
Al2O3	9.5
Fe2O3	10.76
P2O5	36.
SiO2	4.5
C	0.784
Na2O	0.117
K2O	0.274

effluent averaged 130 mg/l of TSS and the secondary effluent averaged 31.2 mg/l. Average ash content of the MLSS was 40.8 percent. Average flow was 0.8 mgd with only a small sidestream (6,900 gpd) sent to tertiary filters. This operating mode allowed for higher ash discharges in the effluent than would have occurred with filtration of the total plant flow and subsequent return of the backwash water to the aeration basin.

In 1975, Gitchel, Meidl and Burant (15) stated the following:

"Any inorganic constituents associated with the carbon that is (sic) derived from either chemically coagulated solids or associated with biological solids remain with the regenerated carbon solids as ash. In a continuous process with repeated regenerations, ash accumulates. Means of controlling the ash build-up -- again beyond the scope of this paper -- have been found."

Data from what was described as a typical spent PAC sludge indicated an ash content of 59 percent. Results of full-scale regenerations of this spent PAC under three conditions indicated ash contents of 68.0, 68.2 and 75.3 percent.

As recently as 1987, it was stated (Enclosures with letter of W. Copa, Zimpro Inc., to Mr. William Sago, August 21, 1987) that, "the original testing of the PACT system with wet air regeneration showed no rapid accumulation of ash. The test work was performed at a treatment plant in the Rothschild area over four-month periods. No ash accumulation was observed during this period. PACT systems have experienced a mixed liquor ash increase followed by operating changes to reduce the ash level. Direct studies of the ash accumulation and development of ash removal technologies were begun only after several PACT installations were in operation."

Study Results

Ash accumulation was a common problem at all full scale PAC/WAR facilities listed in Table 1 when they were operated as originally designed. The size and specific gravity of the ash and PAC particles were found to be similar and effective separation would not occur. As a result, ash was returned to the process from the Lamella settler along with the PAC. Without an effective means of removing ash, the levels in the MLSS would naturally increase. This led to the loss of excess TSS from the secondary clarifiers and significantly increased the loadings on the tertiary filters. Other operational problems related to the ash accumulation included the need for increased MLSS concentrations to maintain an acceptable MLVSS concentration, increased aeration mixing requirements, increased solids loadings on the secondary clarifiers, and plugging of return sludge systems. Most facilities were designed with tertiary filtration and returned filter backwash water to their aeration basins to recover the contained PAC. This practice established an additional recycle loop for fine suspended solids (PAC, ash and/or biomass) with no means other than WAR unit blowdown for removal of this material.

Table 3 summarizes the MLSS ash levels and control methods for the facilities that were reviewed. The ash levels ranged from a low of 30 percent to a high of 82 percent. Various methods were devised by plant operators and the system manufacturer to provide control over ash accumulations. Several facilities cut back on PAC makeup dosages (PAC contains as much as 30 percent ash) to lower levels that would still achieve treatment goals (i.e., nitrification, color reduction, etc.). Experimentation at several plants led to the minimization of PAC addition and, in some cases, its total elimination.

Vernon discontinued PAC addition for several months at a time, but continued to run the WAR system. Mixed liquor was occasionally purged to the primary clarifiers for disposal with the primary sludge. PAC addition was recently reinitiated to control effluent color. Mount Holly discharges a portion of the WAR unit effluent to the primary sludge dewatering system for disposal. East Burlington practices direct dewatering of a WAR reactor effluent slip stream. PAC addition at South Burlington has been discontinued and the plant currently operates as a conventional activated sludge facility. Kalamazoo purged mixed liquor for ash control prior to construction of a differential sedimentation and elutriation (DSE) system to separate ash. Bedford Heights switched to addition of a non-activated carbon (NAC) which is used on a throw-away basis (no WAR system operation). The NAC costs $0.16/lb, which is roughly half the cost of a typical PAC, and is maintained at the minimum concentration needed for satisfactory plant operation. Medina County is operating a modified DSE system and is dewatering the ash with the primary sludge. North Olmsted experimented with several operating modes, with and without WAR

Table 3. Ash Levels and Control Methods at Various PAC/WAR POTWs

Facility	MLSS Ash Content	Ash Control Methods
Vernon	82 %	No PAC addition, periodic purge of MLSS to primary clarifiers.
Mt. Holly	45 %	A portion of WAR discharge wasted to sludge disposal.
E. Burlington	52 %	A portion of WAR discharge wasted to sludge disposal.
S. Burlington	30 %	Ash level after conversion to conventional activated sludge.
Kalamazoo	60 %	New DSE* system recently installed. Ash level is prior to DSE operation.
Bedford Hts.	59 %	Converted to non-activated carbon addition without recovery. Ash level is prior to conversion.
Medina County	40 %	Operating a modified DSE system.
N. Olmsted	60 %	Ash level prior to conversion to conventional activated sludge.
Sauget		Converted to activated sludge.**
El Paso	45 %	Wasting pre-WAR sludge to digesters.

* DSE = Differential Sedimentation and Elutriation.
** Involuntary conversion resulting from catastrophic failure of WAR heat exchanger. Ash was accumulating prior to failure.

unit operation and with and without PAC or NAC addition. They recently switched to conventional activated sludge operation but plan to convert back to the use of NAC. Sauget added PAC during start-up, but a catastrophic failure of a heat exchanger made it impossible to operate their WAR system. The initial PAC dose has since been wasted from the plant. El Paso is wasting a slip-stream of sludge upstream from their WAR reactor to anaerobic digesters.

Net ash accumulation occurs even though a portion of the mixed liquor ash can solubilize in a WAR system. Table 4 summarizes ash solubilization that has either been reported by other researchers or which has been derived from facility operating records where data showing changes in ash content across the WAR unit were available.

TABLE 4. SUMMARY OF WAR SYSTEM ASH SOLUBILIZATION

Source	Percent Ash Solubilization	Reference
Recktenwalt	41	Published (9)
E. Burlington	8	Operating Data
Mt. Holly	-7	Operating Data
Kalamazoo	30	Operating Data

Differential Sedimentation and Elutriation (DSE)

Four of the PAC/WAR systems either have or are in the process of installing DSE systems. A slip-stream of the WAR unit effluent is blended with softened water in an approximate one to four volumetric ratio. Dispersants, such as sodium hexametaphosphate or metasilicate, and an anionic polymer are then added prior to the up-flow elutriation tank. VSS (including PAC) are concentrated and removed in the underflow and the ash fraction is concentrated and exits in the overflow. Cationic polymer addition flocculates the ash and this stream is sent to a clarifier for separation. A filter press is the normal mode for dewatering the concentrated ash underflow.

Zimpro Inc. conducted a number of standardized pilot plant studies of the DSE process to estimate the requirements for full-scale ash removal facilities. Several individual plant balances derived from these DSE pilot studies are presented in Appendix C. Results from DSE studies at seven facilities were used to prepare

the generalized DSE process schematic shown in Figure 3. This Figure presents flow and material balances associated with processing 1000 lb/day of ash through a typical DSE system based on results observed from DSE studies at seven sites. On average, the results indicated that 37 percent ash removal and 90 percent VSS recovery would be reasonable expectations.

East Burlington has a full scale DSE system but, because of the low PAC dosage required for satisfactory wastewater treatment, does not consider it cost effective to operate. Instead of the DSE system, a slip stream of WAR reactor effluent (9 to 10 percent of the WAR flow) is sent to a dedicated filter press for dewatering. The system at Jessup was not in operation at the time this technology evaluation was conducted. A full scale system at Kalamazoo was brought on line in June of 1988. Data from the modified DSE system at Medina were unavailable for incorporation in this evaluation.

Ash Balances and Accumulation

East Burlington and Kalamazoo maintain extensive plant records and also monitor internal sidestreams. Materials balances for several parameters (e.g., TSS, VSS and NVSS) around their aeration basins and WAR units were developed from the operating records at these plants. East Burlington's TSS balance is shown in Figure 4. This balance reflects one year of record. The recycled ash (NVSS) from the WAR unit constituted 83 percent of the ash entering the aeration basins. Ash attributed to biomass growth (1,028 lbs/day) was computed based on the differences between measured influent and effluent ash across the aeration basin and secondary clarifier and the measured difference in aeration basin/clarifier ash content at the beginning and end of the year of record (equivalent to 221 lbs/day). In reality, the 1,028 lbs/day for biomass ash, which is only 6.3 percent of the measured aeration basin influent mass, also reflects any measurement errors in flows or ash concentration. A key feature of Figure 4 is the excellent balance which could be developed.

Figure 5 illustrates the buildup of various MLSS components that was experienced over a 273-day period at the Kalamazoo facility. This operating period does not include the removal of 4 million gallons of mixed liquor from the aeration basins for temporary ash reduction, which occurred in the last quarter of 1986, nor does it include the period of sustained high effluent TSS, which occurred in the last quarter of 1987. The MLCVSS (PAC) concentration was measured by a nitric acid digestion procedure discussed in the next section of this paper. Effluent TSS and VSS concentrations measured during the same period are shown in Figure 6. The mean effluent TSS concentration was 28.6 mg/l and the mean effluent VSS concentration was 14.7 mg/l. During the periods when effluent quality was reasonably satisfactory (April - mid-September), there

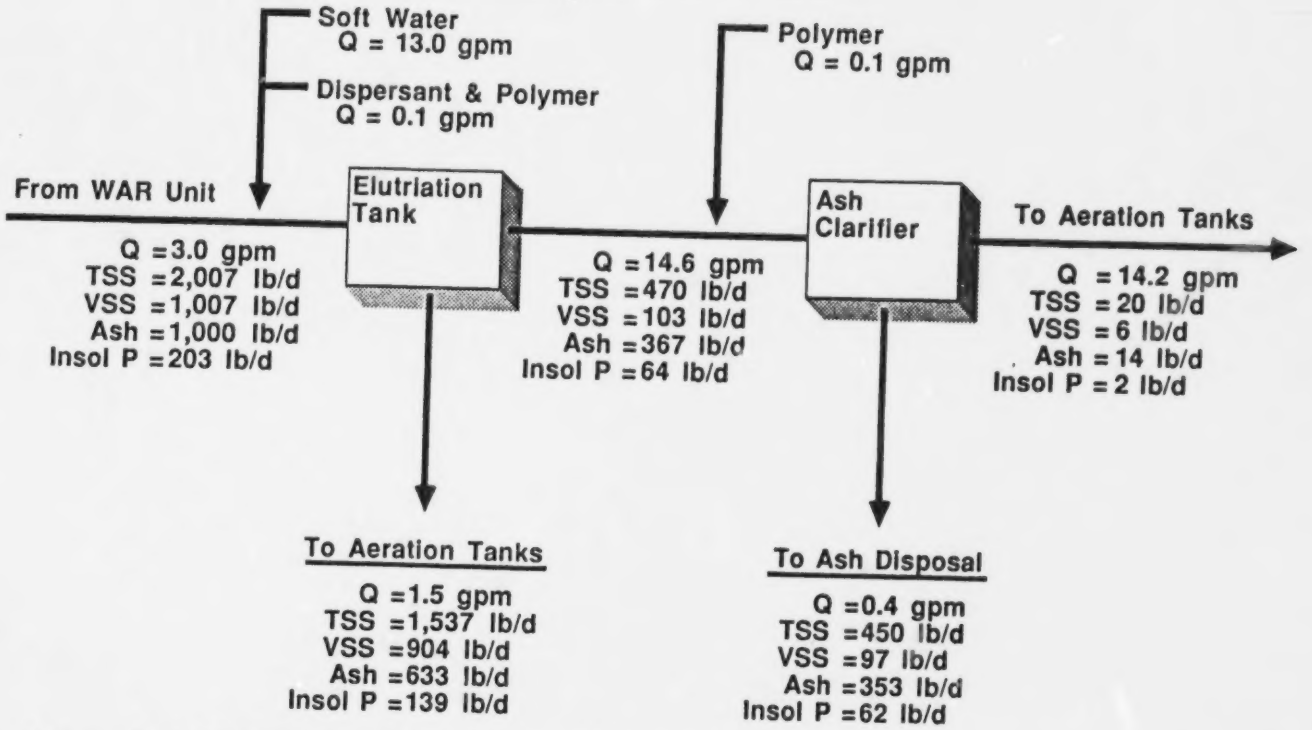
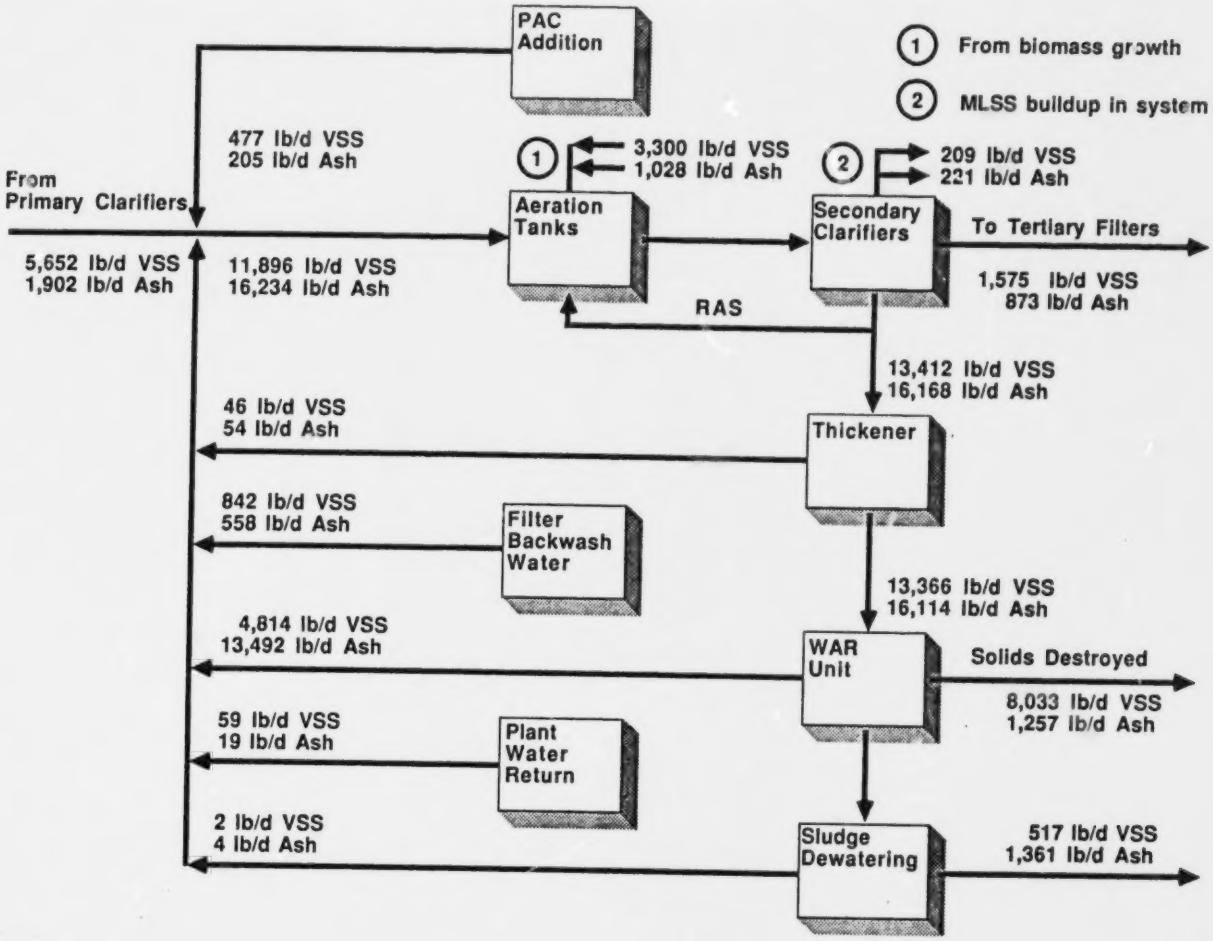
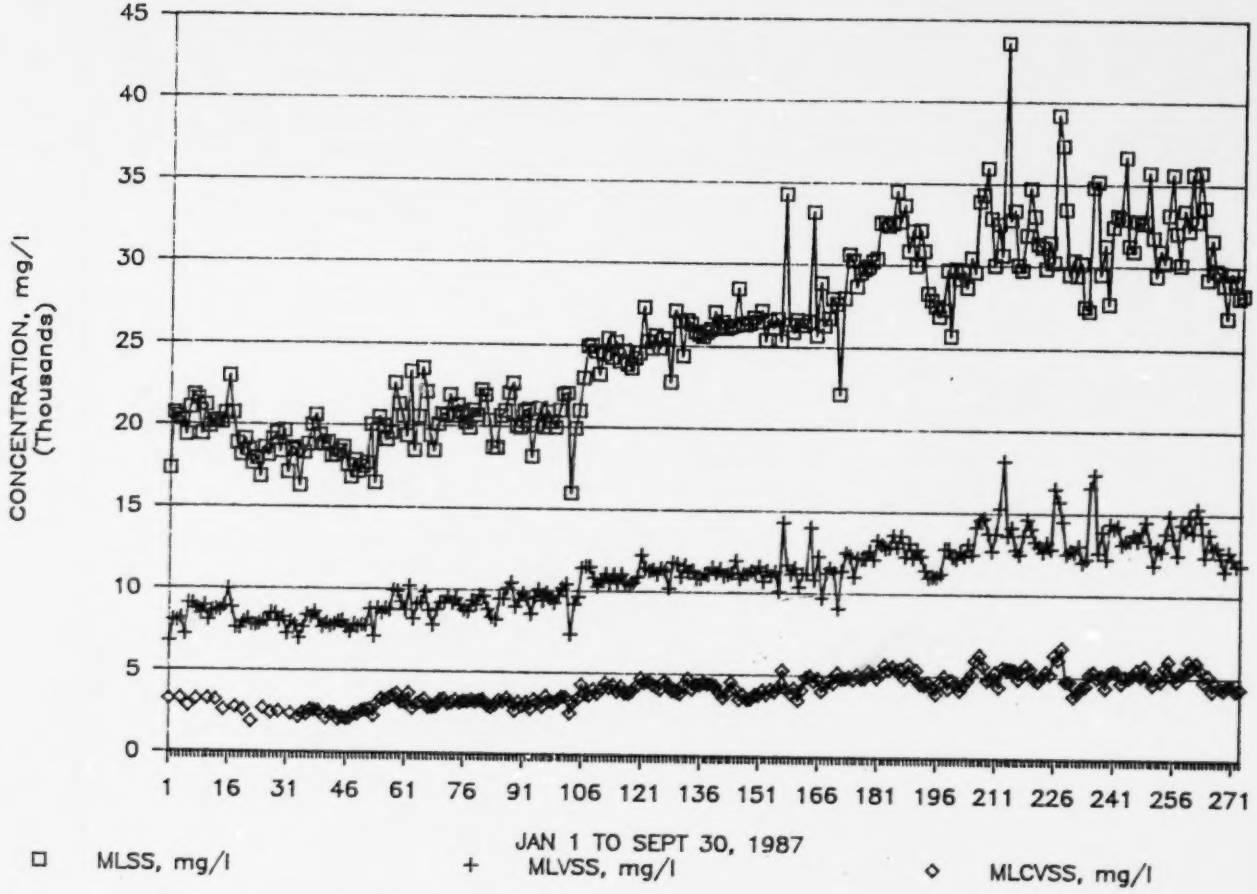


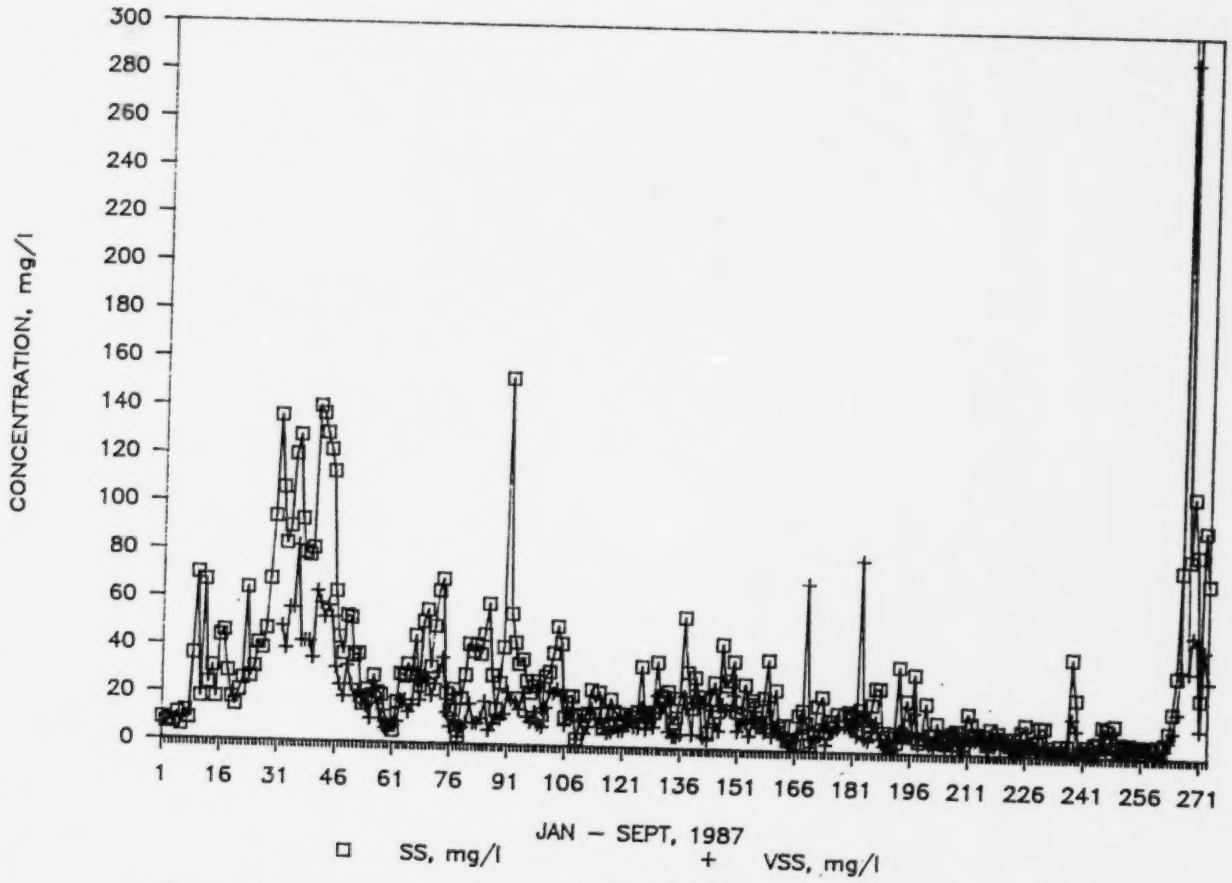
Figure 3. Differential Sedimentation and Elutriation Results from Standardized Pilot Studies



4. Ash and VSS Balances at E. Burlington, NC



5. Aeration Basin Suspended Solids Components at Kalamazoo, MI



6. Final Effluent TSS and VSS at Kalamazoo, MI

was a continuous increase in ash concentration. A linear regression analysis of the entire data set shown in Figure 5 yielded the following values:

PARAMETER	CONSTANT mg/l	X COEFF mg/l	STD ERROR mg/l
MLSS	16,589	68.3	2.3
MLVSS	7,340	27.4	0.89
MLCVSS	2,363	12.0	0.45

The X coefficient is the average daily rate of accumulation in the aeration basin for the indicated parameter.

In addition to the solids accumulation in the aeration basin, there is also an unknown amount of additional solids accumulation in the final clarifier. If one assumes that 80% of the system solids are in the aeration basin and 20% are in the final clarifier the following accumulation rates apply.

PARAMETER	ACCUMULATION RATE, LB/DAY
MLSS	7,268
MLVSS	2,916
MLNVSS	4,352
MLCVSS	1,277

PAC MEASUREMENTS AND LOSS

Analytical Procedures

Plant Measurements

Attempts to construct mass balances for PAC from plant records were unsuccessful. Determination of the PAC content in the mixed liquor is an important process control parameter and the inability to perform PAC balances was deemed significant. This led to a review of the nitric acid test method used to determine the PAC fraction of the MLSS in PAC/WAR systems.

The MLVSS measured in PAC/WAR system aeration tanks may be presumed to include active biomass, biomass residue, nondegradable VSS in the entering wastewater, recycled and virgin PAC, organics bound to the PAC (which are measured as VSS) and any inert VSS formed in and/or not oxidized or solubilized in the WAR process. PAC/WAR plants have traditionally classified all VSS in the aeration basin as either PAC or biomass, with the PAC concentrations measured on an ash free basis. The analytical

method provided to the facilities to differentiate between these two classes of VSS uses the following formula:

$$CVSS = \frac{AMLSS - AMLNVSS}{0.95}$$

where CVSS is the PAC volatile suspended solids concentration, AMLSS is the nitric acid-digested MLSS concentration and AMLNVSS is the nitric acid-digested mixed liquor nonvolatile suspended solids concentration. This calculation assumes that all non-PAC VSS are dissolved by acid digestion.

Nitric Acid Test for PAC

As reported by DuPont (16), virgin PAC and activated sludge samples from several different sources were analyzed by this technique and all biomass did not go into solution. Based on their results (16), an analysis of a 1:1 mixture of PAC and biological solids would have overestimated the CVSS concentration by 18 to 26% with the above calculation method. Clifford (17) reported that the nitric acid digestion procedure could not differentiate between PAC and biomass char formed during his thermal PAC/biomass regeneration studies. Based upon that observation, it can be assumed that the nitric acid procedure will further overestimate the PAC measurement if biomass char is present in a sample.

According to Zimpro personnel (18), the nitric acid digestion technique was developed at Zimpro to attempt to quantitatively determine the biomass and powdered carbon in a mixture. A number of references to the accuracy of this test have been made by Zimpro personnel at various times. These include:

1) The carbon/biomass determination has been stated to be accurate to within 20% if the procedure is carefully followed (Personal Communication, letter of W. Copa, Zimpro Inc. to W. Sago, August 21, 1987).

2) Mr. Copa of Zimpro Corporation further stated (Personal Communication to EPA and Contractors on August 1, 1988) that: a) the nitric acid procedure is accurate to within 10 to 15% in MLSS, and b) the nitric acid digestion procedure has measured PAC concentrations of 1 to 2 g/L in some mixed liquors where no PAC was being added.

3) The Zimpro prepared summary (19) of the DSE study results at Kalamazoo states:

a) In the DSE process, analysis for carbon using nitric acid digestion shows that the recovery of volatile carbon is greater than that of volatile solids. The use of volatile solids in describing carbon recovery is conservative. (pg. 21)

b) Because only a portion of the volatile material in the DSE effluent overflow is powdered activated carbon, the carbon losses are low. Nitric acid digestion techniques were used to better determine the carbon recovery. (pg. 31)

4) The Zimpro prepared American Bottoms report (20) states that during the DSE process testing, analysis for carbon using nitric acid digestion has shown that the recovery of volatile carbon is greater than that of volatile solids. The use of volatile solids in describing carbon recovery is therefore somewhat conservative. (pg. 49)

5) Concerning the DSE system at Kalamazoo, it was stated (Letter of John Berrigan, Zimpro Inc. to Arthur Condren, September 22, 1987) that the carbon/biomass analysis of regenerated carbon slurry (DSE feed) was used for design. In this instance the analysis was referred to as a qualitative guide rather than a quantitative analysis.

6) As shown in Appendix A, the use of the nitric acid procedure for estimating carbon was stated to be highly questionable. Zimpro now states that the nitric acid digestion procedure is not an appropriate test for the regeneration stream.

Plant Operating Results

In addition to using the nitric acid test procedure for process control, several operating facilities also use the nitric acid technique to measure the PAC losses during WAR. The individual measurement results from three facilities where these data were available are presented in Appendix D and are summarized in Table 5.

Nine months of data from both East Burlington and Kalamazoo were analyzed in attempts to establish PAC balances for these facilities. The results of this analysis are presented in Table 6.

There were no long range trends in MLSS concentrations or operating solids retention time (SRT) at East Burlington during the period summarized in Table 6. The average SRT (mass of VSS under aeration divided by the sum of the mass of VSS in the effluent and the mass of VSS to WAR) was only 8.7 days meaning that the period summarized is more than 30 times longer than the SRT.

The original Kalamazoo design made no provisions for wasting solids which accumulated in the system (other than WAR unit blowdown) and this facility experienced increasing solids concentrations during the first 9 months of 1987, as summarized in Table 6 and as previously shown in Figure 5. This increase did not represent a gradual increase in system SRT, which averaged 11.7

TABLE 5. Measured PAC Losses Across Wet Air Regeneration by Nitric Acid Digestion

LOCATION	PERIOD	Measured PAC Loss per WAR Cycle %	Number of Samples
Kalamazoo	2/88 - 5/88	40.6	46
E. Burlington	1/87 - 2/88	30.8	31
Mt. Holly	1/87 - 7/87	32.1	48

Table 6. PAC Balances

Parameter	Kalamazoo, lbs/day	East Burlington, lbs/day
Input		
PAC Added *	3,704	404
Total	3,704	404
Loss + Accumulation		
PAC Accumulation**	1,277	0
PAC in Final Effluent **	1,056	232
PAC Destroyed in WAR **	11,452	1,596
PAC Removed in Filter Press Solids **	0	344
Total	13,785	2,172

* Reported on an ash-free basis.
** Based on nitric acid test procedure.

days for the period. Large effluent TSS losses in January, February and late September (see Figure 6) correlated with the periods of no solids accumulation or small decreases in aeration tank solids. A mass balance on PAC over the period shown in Figure 5, assuming an 80:20 percent solids distribution between aeration tanks and clarifiers, is also presented in Table 6. The computations for effluent PAC VSS assume the effluent VSS have the same percentage PAC as measured for the MLVSS in the aeration basins.

These material balances show that Kalamazoo measures daily losses and accumulations of PAC which exceed the PAC addition rate by a factor of four. East Burlington measures daily PAC losses which are five times higher than the mass of daily PAC addition. Since measurement of the PAC addition rate does not depend on the nitric acid procedure and has been verified through comparison with plant purchase and use records, the average rate of PAC addition is known. Therefore, the nitric acid procedure substantially overestimates PAC concentrations, making the measured value of this parameter of no quantitative significance.

Results of previous VSS destruction studies on wet air oxidation of sludges not containing PAC are shown in Table 7. These data indicate that most, but not all, of the VSS are oxidized or solubilized. A small portion of VSS does not go into solution and, as shown in Figure 1, nondegradable VSS entering the plant which are neither oxidized nor solubilized by WAR must cycle in the system until escaping in the plant effluent or until being removed in a waste stream. Part or all of the gradual buildup in MLVSS at Kalamazoo, as shown in Figure 5, can be attributed to this type of material. Biomass destruction through WAR (measured by the nitric acid test) at Kalamazoo decreased from greater than 96% shortly after start-up in 1985 to an average of 83% during the first five months of 1988. The accumulation of this material contributes to the falsely high values for the measured PAC concentrations.

The absence of a correlation between PAC addition and PAC levels (as measured by the nitric acid procedure) at Kalamazoo is apparent in Figure 7. Ten-day moving averages of PAC addition minus the estimated daily PAC loss (calculated from the effluent VSS values and the measured PAC percentage in the aeration basins) are shown along with the measured ten-day moving average values of mixed liquor PAC concentrations in the aeration basins. There is a gradual rise in the measured PAC concentration which, on a long term basis, is independent of the PAC addition rate. Increasing concentration was not the result of a gradual increase in system SRT.

As inferred from the information in Table 8, the WAR reactor effluent contains a substantial fraction of material measured as "biomass" that is really just VSS which did not go into solution. Since the material balances have shown that the PAC fraction is

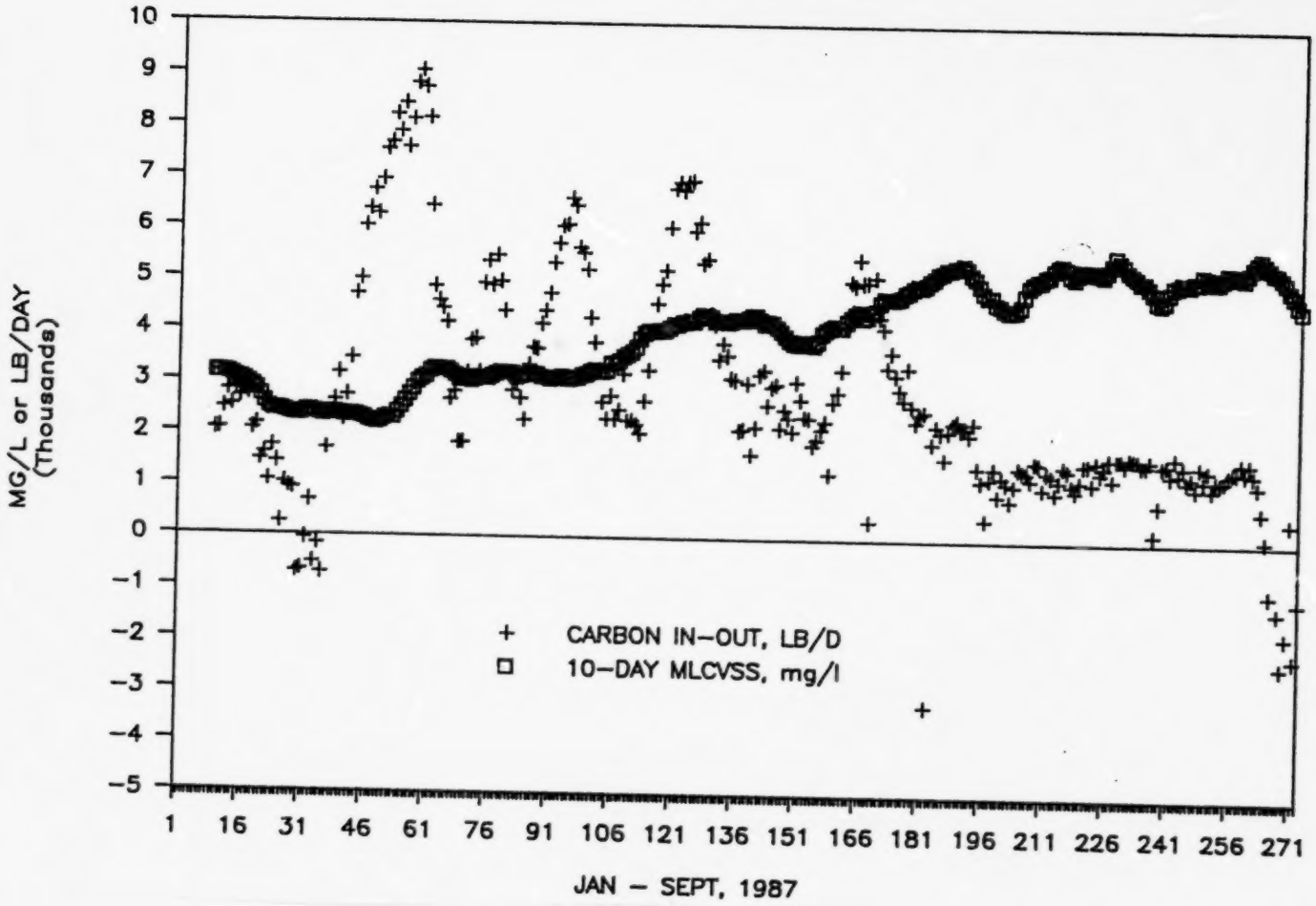


Figure 7. Ten Day Moving Averages of PAC Addition Less Loss and Measured Aeration Basin Levels at Kalamazoo, MI

TABLE 7. REDUCTION IN VSS WITH WET AIR OXIDATION

Temperature, °C	VSS Reduction, %	Reference
260	93	(5)
197-220	79-85	(21)
180-246	72-97	(22)
200-250	47-91	(23)
240	89	(7)
260	89	(8)
200-230	72-89	(24)

TABLE 8. Characterization of VSS from WAR

Facility	% PAC*	% Biomass*
E. Burlington	79.0	21.0
Kalamazoo	67.7	32.3
Mt. Holly	79.2	20.8

*As measured by the nitric acid procedure

substantially overestimated by the nitric acid procedure, the actual quantity of this non-descript volatile suspended material is even higher than indicated by the analytical procedure. Material balance calculations for East Burlington and Kalamazoo suggest that about five to six percent of the sum of the primary effluent volatile suspended solids plus new biomass growth are not oxidized or solubilized by WAR and do not further degrade upon return to the aeration basin.

PAC LOSS BY WAR

The data summarized in Table 5 indicate PAC losses across WAR units to be in the range of 30 to 40 percent per regeneration. However, as shown in Table 6, the magnitude of the PAC loss exceeds by four to five fold the amount of PAC added, meaning that the absolute values of the PAC concentration measured by the nitric acid digestion technique are meaningless. Whether or not the relative change of 30 to 40 percent represents the actual percentage loss cannot be determined from the data available.

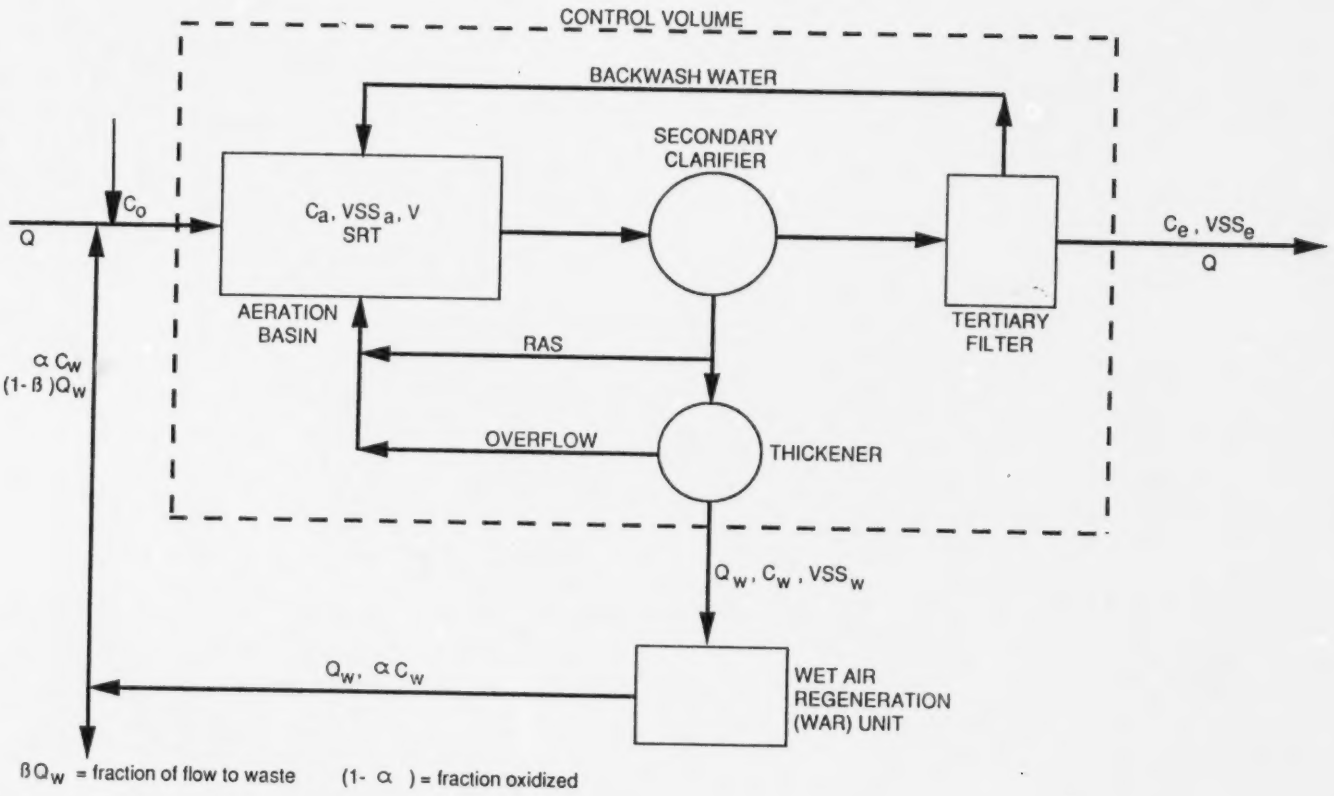
In previous pilot studies of PAC systems with WAR, Zimpro reported low PAC losses through WAR (20, 25). For example, results reported from Back River (25) stated that the WAR unit operated with PAC recovery efficiencies in excess of 95 percent. In an attempt to ascertain the reason for the large variations between the Back River results and those observed at the three facilities summarized in Table 5, a detailed analysis of the Back River report was undertaken. The results are shown in Appendix E. It can be seen that the conclusion concerning low PAC losses was not based on total use of the nitric acid test procedure to measure changes across WAR, but on a procedure which was claimed to be more precise. The nitric acid test was used to measure "PAC" everywhere except across WAR and then the sum of all losses (effluent, blowdown, spills, etc) including the measured amount of PAC in the reactor at the end of the study was subtracted from the amount of PAC added. Since the nitric acid procedure overestimates the PAC concentration in all measured samples, this led to an underestimate of the PAC consumed by WAR. Ash balance data at Back River suggest actual PAC losses through WAR to have been about 43% for the entire period.

Recktenwalt (9) conducted laboratory studies on regeneration of PAC and biomass mixtures. A series of 12 regenerations was run in which new biomass was added to each cycle as follows:

a) virgin PAC for the first cycle
b) recycled WAR product for the second and third cycles, and
c) a mixture of recycled product and virgin PAC for cycles 4-12.

Based on the assumption that all biomass was destroyed, the reported PAC destruction (based on TOC measurements) averaged 12.9% per cycle.

The same nine months of plant data from East Burlington used to develop Table 6 can also be used to demonstrate how the PAC concentrations measured in the aeration basin will change as a function of PAC loss through WAR. The control volume shown in Figure 8 is applicable to the East Burlington facility where both thickener overflow and filter backwash are returned to the aeration



8. PAC Control Volume for E. Burlington

basin. The fraction of flow diverted to the filter press for disposal is given by βQ_w.

SRT is defined as

$$SRT = \frac{C_a V}{Q_w C_w + Q C_e}$$

where C_a, C_w and C_e are PAC concentrations in aerator, in the flow to WAR (Q_w) and in the effluent flow ($Q_e = Q$), respectively, and V is the aerator volume. If the ratio of PAC:VSS is equal in these streams then,

$$\frac{C_a}{VSS_a} = \frac{C_e}{VSS_e} = \frac{C_w}{VSS_w}$$

At steady state, the concentration of PAC in the aerator is given by

$$C_a \left\{ \frac{V}{SRT} - \alpha(1-\beta)\frac{V}{SRT} + \alpha(1-\beta)\frac{QVSS_e}{VSS_a} \right\} = QC_o$$

where C_o is PAC dosage based on influent flow, α is the fraction of PAC not oxidized in WAR and β is the fraction of Q_w diverted to waste after WAR.

Calculated vs. measured aerator PAC values for East Burlington are compared in Table 9. The plant data represent mean values for 9 months of operation. If no PAC is lost by WAR, the mean PAC values measured in the aeration basin overestimate the actual PAC concentration by 67 percent. With a 15 percent loss by WAR, which is a value close to the results reported by Recktenwalt (9), aerator measurements based on the nitric acid procedure overestimate PAC by 215 percent. If the actual percentage loss across WAR was 30.8 percent, as determined by the mean of the nitric acid measurements shown in Table 5 for this facility, the aerator PAC concentration is overestimated by 373 percent. This type of analysis demonstrates not only that the PAC concentrations measured across WAR are meaningless, but also that the PAC concentrations measured in the aeration basin at East Burlington are substantially higher than could possibly be present.

TERTIARY FILTRATION

Tertiary filters were installed in nearly all of the municipal PAC/WAR facilities even though several facilities have an effluent TSS limit of only 30 mg/l. Table 10 summarizes the average monthly performance of effluent filters for selected operating periods at East Burlington, Kalamazoo and Mt. Holly. Solids capture in secondary clarification was not adequate at East Burlington or Kalamazoo to consistently meet the discharge permit indicating the key role played by the tertiary filters at these locations. Polymer assisted clarification was normally used at the various

TABLE 9. Calculated vs. Measured PAC levels at E. Burlington

Plant Data:

MLVSS, mg/l	4750
Basin volume, MG	2.917
Influent flow, MGD	6.48
SRT, days	8.72
VSS_e, mg/l	12
C_o, mg/l	7.47
Q_w, gpd	37803
VSS_w, mg/l	39985
ß	0.0945

Fraction Pac Oxidized	Calculated Aerator PAC, mg/l	Measurement Error*, %
0.0	1042	67
0.05	796	117
0.15	540	215
0.308**	360	373

*Error = (Measured Value - True Value)/True Value
Measured Value = 1702 mg/l
**Mean of Nitric Acid Test Measured Loses

facilities. Typical polymer costs were estimated at $21,000/yr/MGD based on an applied dosage of 2.75 mg/l and a unit cost of $2.50/dry lb.

As indicated in Figure 1, the backwash from the tertiary filters was commonly returned to the aeration basin inlet with the intent of maximizing carbon recovery. This practice also results in the continual return of inert ash to the aeration basin. Returning tertiary filter backwash to the aeration basin is normally avoided in conventional treatment systems because the fine solids captured by the filters have already resisted settling in the secondary clarifiers and their return to the secondary process would not be expected to improve their settling performance. Typical practice in conventional facilities is to return the backwash upstream of the primary clarifiers.

RECYCLE LOADINGS

Past studies of primary and secondary sludge treatment with wet air oxidation systems (23, 26) indicated that 25 to 40 percent of the COD remains in the system effluent when oxidation temperatures are in the range of 230 to 245°C. Most of this

TABLE 10. TERTIARY FILTER PERFORMANCE

Observation No.	Secondary Effluent TSS, mg/l	Filter Effluent TSS, mg/l	TSS Removal %
1	13	7	46
2	13	7	46
3	24	8	67
4	41	14	66
5	14	5	64
6	27	10	63
7	30	11	63
8	34	13	62
9	31	8	74
10	61	21	66
11	32	15	53
12	30	14	53
13	9.9	5.1	48
14	14	15.3	--
15	22	16.9	23
16	21	6.2	70
17	28	6.8	76
18	26.5	9.1	64
19	22	--	--
20	36	13	64
21	34	8	76
22	94	27	71
23	101	46	54
24	128	61	52
25	98	60	39

NOTES:
1. Obs. Nos. 1-12 for the Period 8/86-7/87 E. Burlington, NC
2. Obs. Nos. 13-19 for the Period 1/87-7/87; Mount Holly, NJ
3. Obs. Nos. 20-25 for the Period 7/87-12/87; Kalamazoo, MI

material is in the form of soluble, low molecular weight alcohols, aldehydes and acids which are biodegradable. The BOD_5:COD ratio of these compounds is about 0.55 (8, 26, 27).

PAC systems also have a high mass of organics, nitrogen and phosphorus in the WAR reactor effluent as shown by the data in Table 11. The WAR return stream can represent a significant portion of the loading applied to the secondary process. Organic (BOD5) recycle loading ranged from 11 to 29 percent of the primary effluent loading and the NH_3-N loading ranged from 54 to 120 percent at these two facilities.

Kalamazoo monitors total phosphorus in the WAR return stream. The concentration is high and represents 730 percent of the mass loading from the primary clarifier. This facility has a phosphorus limitation and adds alum to the secondary system for its precipitation. The precipitated phosphorus compounds and that resulting from cellular destruction by WAR have concentrated as an insoluble, inert recycled material.

As indicated in Figure 4, ash constitutes a major recycle loading to the secondary process. Contributions from the WAR unit discharge, tertiary filter backwash water, thickener overflow and sludge dewatering operations is over 8 times greater than the ash content of the primary clarifier effluent.

TABLE 11. Recycle Loadings From WAR

Facility	BOD5		NH3-N		Total-P	
	lbs/d	mg/l	lbs/d	mg/l	lbs/d	mg/l
E. Burlington						
Recycle	2,450	2,938	461	5,528		
P.E.	8,360	156	382	7		
% of P.E. Load	29		120			
Kalamazoo						
Recycle	7,853	4,400	2,195	1,230	9,459	5,300
P.E.	71,384	334	4,046	19	1,219	6
% of P.E. Load	11		54		730	

P.E. = Primary effluent.

ADSORPTIVE CAPACITY OF RECYCLED PAC

In addition to the inability to measure true PAC concentrations, it is difficult to characterize the adsorptive capacity of the material exiting the WAR system. Attempts to characterize the regenerated PAC from the Sauget pilot study (20) showed that the COD adsorption capacity was too low to measure. It was concluded that comparison of virgin and regenerated PACs was not an appropriate indicator of performance.

Recktenwalt (9) reported that PAC subjected to multiple regenerations does not retain significant capacity for adsorption of low molecular weight compounds such as 2,4-dinitrophenol. This loss of capacity was attributed to surface oxide accumulation on the PAC. For compounds such as these, Snoeyink (Personal Communication, letter of V. Snoeyink to Arthur Condren, September 14, 1987) indicated that removals were largely dependent on the virgin PAC dosage and the fraction of the PAC that had only been through the WAR unit once. On the other hand, methylene blue adsorption after regeneration was essentially the same as for virgin PAC. Materials that have adsorptive properties similar to methylene blue should adsorb as well to the recycled VSS as to virgin PAC.

METALS ACCUMULATION

Activated carbon will adsorb some heavy metals. The rate and extent of removal depends upon carbon type, pH and surface loading (28). This removal mechanism could help to reduce the toxicity to biological functions in PAC/activated sludge systems.

In the PAC/WAR system configurations shown in Figure 1, all PAC bearing sidestreams (thickener overflow and filter backwash) in addition to the WAR unit effluent are returned to the aeration basin to maximize the recovery of PAC. Heavy metals contained in these streams are likewise returned. Through repeated cycles, a concentration mechanism for heavy metals is established.

One facility (Bedford Hts.) experienced operating and effluent quality problems that were attributed to heavy metals accumulation (29). Table 12 summarizes the heavy metal concentrations that were observed. This facility later controlled ash and ash associated heavy metal accumulations through substitution of the PAC with NAC and abandoning attempts at media recovery.

The Vernon facility noted high metals concentrations in the blend of primary and waste secondary sludge fed to the vacuum filters (See Table 13) and conducted an EP Toxicity Extraction to determine the RCRA status of the sludge. Results of the EP Toxicity Extraction Analyses (30) shown in Table 14 indicated that the metals did not leach appreciably under conditions of the test.

Table 12. Heavy Metal Concentrations Observed at Bedford Hts. (29)

Parameter	Raw, mg/l	MLSS, mg/l	Final, mg/l
Cadmium	0.019	0.269	0.009
Chromium	0.095	68.9	0.05
Copper	4.8	51.75	0.377
Lead	0.48	8.7	0.04
Nickel	0.29	13.57	0.18
Zinc	15.91	189.0	1.58
Iron	23.14	1440.0	4.78

Table 13. Metals Analyses at Vernon, CT

Parameter	WAR Feed ug/l*	Pri & Sec Waste** ug/l*
Ag	27.6	30.1
As	48.7	34.7
Ba	481.	538.1
Cd	3.0	3.6
Cr	156.	169.
Cu	649.	688.
Hg	0.8	1.04
Ni	48.7	38.3
Pb	438.	496.
Se	59.4	64.5
Zn	1,040.	1,149.

*Dry weight basis
**Average of two analyses

Table 14. EP Toxicity Metals Analyses at Vernon, CT

Parameter	WAR Feed mg/l	Pri & Sec Waste* mg/l
Ag	ND	0.009
As	ND	0.22
Ba	0.100	0.118
Cd	0.018	0.015
Cr	0.018	0.038
Hg	ND	ND
Pb	ND	0.147
Se	ND	ND

*Average of Two Analyses
ND = Not Detected

Vernon practices land application for sludge disposal on a periodic basis. Land application guidelines establish maximum total metal loading limits for the life of a disposal site. The high observed total metal concentrations in the waste sludge will significantly limit the life of a land application site.

OXYGEN TRANSFER

Previous studies reported that oxygen transfer efficiency (OTE) for PAC aeration systems would be higher than for conventional activated sludge systems, leading to at least a 20% savings in aeration power. This was attributed to an expected high alpha value (31). Offgas testing at El Paso determined alpha values of 0.24 to 0.28 for the first stage aeration system and 0.52 to 0.65 for the second stage aeration system (Boyle W., Personal Communication, September, 1988). These values are in the low-to mid- range for conventional activated sludge systems. Since the sizing of the aeration system at El Paso was based upon a higher alpha value than was determined to be applicable, the City was awarded a 100% M/R grant to upgrade the aeration system. Data on the OTEs at other full scale PAC/WAR systems were not available.

O & M CONSIDERATIONS

A WAR unit is comprised of high temperature and high pressure components. Such equipment is not routinely found in municipal wastewater treatment applications. Special skill levels are required to operate and maintain such components. Operating temperature/pressure conditions require that repairs (such as welding) be performed by certified craftsmen and that all repairs be completed in such a manner that the pressure and temperature rating certifications are maintained.

Operation of a WAR system requires a working knowledge of boiler water chemistry. Several facilities experienced coil failures in their WAR system boilers that were reported to be the result of inadequate deoxygenation of boiler feed water.

Other facilities experienced frequent failure of high pressure valves which required replacement of trims and seats. Different theories were presented to explain the failures including high exit velocities, abrasion from the PAC and ash, transient pressure conditions and non-uniform coefficients of thermal expansion for different valve components. A design modification to utilize ceramic components has decreased the failure rate at some facilities. Kalamazoo and Mount Holly have located alternative suppliers which has resulted in valve component increased service life and reduced cost. North Olmsted had difficulty in obtaining replacement components, some of which had a 52 week delivery schedule due to the special nature of the alloys specified by the system manufacturer.

Scale formation in the WAR reactor was reported by several facilities. Formation was severe at some plants, resulting in limited throughput capacity and decreased operating temperature. Scale formation continued to occur in some plants that regularly acid cleaned their WAR systems. Manual removal of scale with water lasers has been required at some facilities. Figure 9 is a photograph of a section of scale which was removed from the WAR unit at North Olmsted. Under close scrutiny, the accumulation shows multiple layering of deposits which is believed to represent each operating cycle of the WAR system.

Significant scum accumulation on the surface of secondary clarifiers was experienced at three facilities. The cause(s) for these accumulations has not been determined.

Additional O&M considerations included frequent maintenance on the last stage of multi-stage air compressors, abrasion related repairs to slurry transfer pumps and check valve problems on high pressure feed pumps.

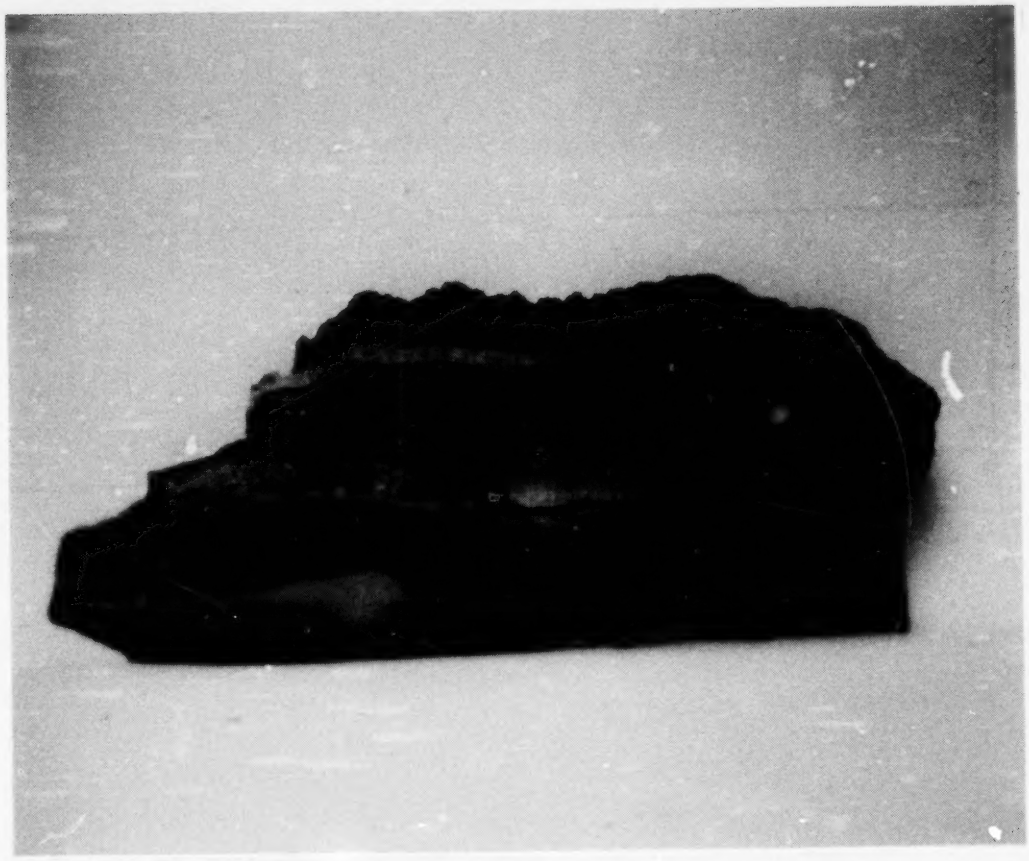


Figure 9. Scale Buildup in WAR at N. Olmsted, OH

SECTION 7

ECONOMIC CONSIDERATIONS

A few facilities maintained separate records of the costs associated with WAR system operation and maintenance. Average monthly O&M costs in 1986 for one facility which processed an average of 42,000 gpd containing 26,300 lbs/d of TSS through their WAR unit are shown in Table 13. These costs represent an average of $21.86/1,000 gals or $35.13/1,000 lbs of TSS processed through the WAR unit. Another plant that also maintained separate cost records computed 1986 WAR processing costs (fuel, water, electric @ $.07/Kwh, repairs and labor) to be $27.68/1,000 gals or $50.88/1,000 lbs of TSS.

Table 14. WAR O&M COSTS

Item	Cost, $/Month
Parts	5,234
Electricity*	10,448
Fuel Oil	1,846
Cleaning Chemicals	1,140
Labor	9,082
Total	27,750

*Based on $0.046/Kwh

Bedford Heights maintained detailed records of WAR operating costs. For an eleven month period in 1986, the WAR unit processed 2.58 million gallons at an average cost of $42.00/1,000 gal. This cost was developed based on manpower at $11.60/hour, natural gas at $5.10/MCF, electricity at $0.068/Kwh, water at $11.35/MCF and actual WAR unit material costs (lubricants, contractor repair services and all repair parts). The cost was equivalent to $75.58

per 1,000 lb processed. Bedford Heights also operates an LPO unit for primary sludge conditioning. The 1986 LPO operating costs (labor, utilities, repairs) were $15.00/1,000 gal conditioned in this unit.

Bedford Heights considered installing a DSE system during their cost effectiveness analysis of options to address ash buildup problems (29). Instead, they chose to substitute NAC for PAC and waste the excess biomass/NAC mixture to the primary clarifiers. The combined sludge is now conditioned in the LPO unit and the WAR unit is no longer operated as such. They have proposed to convert the WAR unit to an additional LPO unit.

The economic analysis performed for the retrofit DSE system at Kalamazoo assumed that all VSS which exited the WAR system were PAC (19). Based on the nitric acid procedure, the PAC content is only 68 percent of the total VSS (Table 8). However, based on the mass balances presented earlier, it is clear that the actual PAC concentration is substantially less than that measured by this testing procedure. Since there is no analytical procedure available for the determination of true PAC content, the cost effectiveness of the Kalamazoo DSE system cannot be accurately determined on the basis of the reported value of the PAC that is recovered by the system. Estimated capital and operating costs were developed for the DSE system (Personal Communication, Letter and Attachments from Sheryl Sculley to Mr. Brian Myers, March 3, 1987). However, if the cost/benefit analysis is recalculated and based on nitric acid measurements (which also overestimate PAC concentrations) instead of on total VSS recovered, the benefits of the system over an assumed 20-year operating life are questionable. In this case, however, as for East Burlington, the manufacturer bore the majority of capital costs for the DSE system.

Operating costs for DSE systems include those associated with water, water softening, dispersant and dual polymer application, power and labor. Manufacturer pilot studies were used to project this cost to be approximately $20/1,000 gals of material processed. Given the inaccuracy of the estimates of PAC content, it is difficult to determine the benefit of a DSE system operation over direct wasting of a fraction of the material, as is practiced by several facilities. Insufficient data are available from the recently constructed full-size Kalamazoo DSE facility to determine the cost/benefit associated with the operation.

REFERENCES

1. Hutton, D. G. and Robertaccio, F. L., U.S. Patent 3,904,518, September 9, 1975 and U.S. Patent 4,069,148, January 17, 1978.

2. PACT Wastewater Treatment Service, Applications and Evaluation, Technology Manual/Volume 1, E. I. duPont de Nemours and Co., Wilmington, Delaware (1981).

3. Wastewater Treatment Systems Manual 200, Zimpro Inc., Rothschild, Wisconsin (1984)

4. Ng, A., Stenstrom, M.K. and Marrs, D.R., "Nitrification Enhancement in the Powdered Activated Carbon-Activated Sludge Process for the Treatment of Petroleum Refinery Wastewaters", Jour. Water Poll. Control Fed., 59, 199 (1987).

5. "Sludge Treatment and Disposal by the Zimmerman Process", 23rd Progress Report of the Committee on Sanitary Engineering Research of the Sanitary Engineering Division, SA4, Jour. San. Eng. Div., ASCE, 13 (1959).

6. McDonald, J.R. et al., "Wet Air Oxidation of Sludge at Hockford Sewage Works", Effl. and Water Treat. Jour., (G.B.), 14, 13, 1974.

7. Harding, J.C. and Griffin, G.E., "Sludge Disposal by Wet Air Oxidation at a Five MGD Plant", Jour. Water Poll. Control Fed., 37, 1134 (1965).

8. Hurwitz, E. and Dundas, W.A., "Wet Oxidation of Sewage Sludge," Jour. Water Poll. Control Fed., 32, 918 (1960).

9. Recktenwalt M.A., "Wet Air Regeneration of PAC in the PAC/Activated Sludge Process", M.S. thesis, Environmental Engineering in Civil Engineering, University of Illinois, Urbana,IL (1986)

10. "Powdered Carbon: Right Combination At Tight Times", Reactor, 57, Zimpro, Inc., June 1986.

11. Bendt, C.L., Wet Air Regeneration of PAC, presented at the International Conference on Application of Adsorption to Wastewater Treatment, Vanderbilt University, February, 1981. Zimpro Technical Report Number W-613.

12. Deeny, K.J., Heidman, J.A., and Condren, A.J., "Evaluation of Full Scale Activated Sludge Systems Utilizing Powdered Activated Carbon Addition with Wet Air Regeneration", presented at The Water Pollution Control Federation Conference, Dallas, Texas, October, (1988).

13. Knopp P.V. and Gitchel W.B., "Wastewater Treatment With Powdered Activated Carbon Regenerated By Wet Air Oxidation". Proceedings of the 25th Purdue Industrial Waste Conference, West Lafayette, IN, May 1970, Part II, 687 (1970).

14. Burant, W. Jr., and Vollstadt T.J., "Full-Scale Wastewater Treatment with Powdered Activated Carbon," Water and Sewage Works, November, 42 (1973).

15. Gitchel W.B., Meidl J.A. and Burant W., "Powdered Activated Carbon Regeneration by Wet-Air Oxidation." AIChE Symposium Series, Water-1975, 71, No. 151, 414 (1975).

16. "Evaluation Procedures for Sludge", Appendix C in Design, Startup and Operation of a PACT Plant, Technology Manual/Volume 2, E.I. duPont deNemours and Co. (1981).

17. Clifford D., et al., "Thermal Regeneration Of Powdered Activated Carbon (PAC) And PAC-biological Sludge Mixtures." Water Research 17, 1125 (1983).

18. Knopp, P.V., et al., "Wet Oxidation Regeneration", in Carbon Adsorption Handbook, edited by P. N. Cheremisinoff and F. Ellerbusch, Ann Arbor Science Publishers, Ann Arbor, MI, (1978).

19. "Ash Removal Carbon Recovery System Testing and Proposed Full-Scale Design For The Water Reclamation Plant, Kalamazoo Michigan", Zimpro Inc., August (1986).

20. Vollstedt,T.J. and Berrigan, J.K., "Evaluation of Ash Removal from a PACT/WAR Pilot System at the American Bottoms RWWTP", Zimpro Inc., Rothschild, Wisconsin, July (1987).

21. Brooks, R.B., "Heat Treatment Of Activated Sludge", Water Pollut. Control,(G.B.), 67, 592 (1968).

22. Takamatsu, T., et al., "Model Identification of Wet-Air Oxidation Process Thermal Decomposition." Water Research, 4, 33 (1970).

23. Teletzke, G.H.,et. al., "Components of Sludge and Its Wet-Air Oxidation Products," Jour. Water Poll. Control Fed., 39, 994 (1967).

24. Gitchel, W.B., et al., "Characteristics of Active Carbon Regeneration by Wet Oxidation", Presented 70th AIChE Convention, New York (1977).

25. Pilot Activated Sludge and Powdered Carbon Enhanced Activated Sludge Study at Baltimore, Maryland's Back River WWTP, prepared by Zimpro Inc., Rothschild, Wisconsin.

26. Hurwitz, E. et al., "Wet Air Oxidation of Sewage Sludge", Water and Sewage Works, 112, 298 (1965).

27. Erickson, A. H. and Knopp, P.V., "Biological Treatment of Thermally Conditioned Sludge Liquors", Proc. 5th IAWPR International Conference, Vol. 1, Paper II-33/1-15 (1970).

28. Corapcioglu, M.O., Huang, C.P., "The Adsorption of Heavy Metals Onto Hydrous Activated Carbon", Water Research 21, 1031, 1987.

29. URS Dalton, "Final Report on Ash Removal Pilot Plant Study at Bedford Heights, Ohio", May (1987).

30. 40CFR Part 261, EPA Procedure 13-10.

31. Meidl, J.A. "Application of PACT to Municipal Wastewaters." presented at The International Conference on Application of Adsorption to Wastewater Treatment, Vanderbilt Univ., February (1981),Zimpro Bulletin W-612.

APPENDIX A

PREVIOUS COMMENTS FROM PAC PROCESS MANUFACTURER (ZIMPRO)

ZIMPRO
PASSAVANT

Zimpro systems
Passavant equipment
Hydro-Clear® filters
A member of The Ventures Group

INNOVATIVE WASTE TREATMENT TECHNOLOGY

October 25, 1988

Mr. Peter E. Shanaghan
Office of Municipal Pollution Control
United States Environmental Protection Agency
401 M. Street S. W. (WH-595)
Washington, D.C. 20460

Dear Mr. Shanaghan:

We appreciate the opportunity to comment on the paper "Evaluation of Full Scale Activated Sludge Systems Utilizing Powdered Activated Carbon Addition With Wet Air Regeneration" by Deeny, Heidman, and Condren, delivered at the 61st annual meeting of the Water Pollution Control Federation in Dallas on October 3, 1988. We applaud the efforts being undertaken to evaluate treatment processes and, in particular, we support the paper's stated objective of documenting the performance of plants using the PACT/WAR technology.

Research on the PACT/WAR system can provide an important contribution to the technical literature and can be useful in the evaluation of treatment processes needed for our nation to reach its clean water objectives. Given the importance of research in this area, however, Zimpro/Passavant has a number of concerns about the analytical methods and the quality of the data used in this research. Simply put, the study sought to reach conclusions that current analytical methods and the base of experience with PACT/WAR technology will not support. As a result, the conclusions are flawed in at least three areas: carbon losses, cost effectiveness and ash accumulation and removal.

1. Carbon Usage

The paper concludes that losses of carbon across the PACT/WAR system are much greater than anticipated. The paper's carbon loss conclusions are, however, undercut by two substantial problems.

First, the paper's weakest link is the highly questionable use of the nitric acid digestion procedure for estimating carbon. Both the discussion on carbon usage and losses in PACT/WAR systems and the cost effectiveness analysis hinge to a great extent on this analytical procedure. Yet, the authors candidly admit that the nitric acid digestion procedure -- a standard test for determining the carbon and biomass content of mixed liquor -- cannot accurately measure the carbon content of the regenerated stream.

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Telex 29-0495

We agree that nitric acid digestion is not an appropriate test for this stream. Having stated that the test cannot accurately measure carbon content, however, the authors assume without any appropriate scientific or engineering reference that the test "over estimates" the amount of regenerated carbon contained in the stream, and proceed to base a whole series of critical conclusions on this assumption. This analytical process is contrary to normal Agency decision making procedures as well as good research procedures. If the analytical procedure utilized by the authors yields inconclusive results, as the authors admit, then the assumptions regarding the results must also be considered inconclusive. Furthermore, the authors cite work by Clifford to support the claim that the questionable test over estimates regenerated carbon amounts. However, when analyzed it is clear that Clifford's work was performed on the products of a dry thermal regeneration process, which is much different from wet air regeneration and cannot support the over estimation conclusion. This weakness in the nitric acid digestion procedure renders the paper's estimates for both carbon loss and cost effectiveness unreliable as a basis for analysis or regulatory decision making.

Second, the paper frequently implies carbon losses by reviewing carbon addition data at various PACT/WAR plants. Although carbon levels are difficult to measure, the carbon addition data in the paper are particularly misleading and do not support the broad conclusion about carbon loss.

Various plants add and use carbon at different times and at differing rates, depending upon local conditions and treatment objectives. The paper's conclusions, however, fail to account for this variability. For example, the Kalamazoo, Michigan, plant cited by the authors took several million gallons of mixed liquor into storage at the end of 1986 to reduce the amount of ash cycling in the process. Because the mixed liquor contained a substantial amount of powdered carbon, this created a temporary carbon shortage which was countered by increased carbon additions in early 1987. The authors, missing this action, suggest that although the plant reduced its carbon addition rates during the middle of 1987, the system experienced major carbon accumulations. Had the authors included data for the entire year 1987, they would have seen reductions in the carbon levels as the system regained a steady state condition in the third and fourth quarters. Thus, a critical error in analysis of relevant factors has led to an erroneous conclusion.

A second example arises from the failure of the authors to consider the impact of enforcement of local pre-treatment regulations. Variances in this area among plants may result in reduced flows of toxics into various PACT/WAR facilities thereby lowering the carbon needed to meet

requirements. In the case of South Burlington, where the anticipated industrial wasteload never materialized, carbon has been eliminated altogether since the plant can meet its permit with a conventional activated sludge process.

An accurate and complete assessment of carbon usage should account for such variability in usage and not compound the inherent inaccuracy of the nitric acid digestion procedure as a test of the regenerated carbon stream.

2. Cost Effectiveness

Accurate cost information remains the most meaningful way to evaluate the effectiveness of a wastewater treatment process, yet the paper treats this important topic superficially. The only data reported are lump sum operational costs from three (3) of the eleven (11) WAR (regeneration) systems installed to date. These numbers are not compared to those for comparable treatment technologies. In fact, the only comparison made for WAR costs is against those for low pressure wet air oxidation. These two systems are not comparable, however, because low pressure oxidation conditions sludge solids for ultimate disposal, whereas the higher pressure WAR units regenerate carbon and destroy sludge solids. The end results differ greatly, and costs to operate the two kinds of systems can be expected to differ, as well.

A thorough cost effectiveness review should include operating costs at all operating PACT/WAR plants, should credit all the functions of the PACT/WAR system, and should compare costs with comparable technologies. Failure to consider such factors results in the inaccurate and misleading cost effectiveness analysis set forth in the current paper. The authors concede that every operating plant has made appropriate changes to resolve the ash accumulation problem.

3. Ash Accumulation

However, the paper did not adequately evaluate the important technique of Differential Sedimentation and Elutriation (DSE) method of ash/carbon separation. The DSE method is currently being employed at Kalamazoo, Michigan, and Medina County, Ohio, and may be the answer to the problem of ash buildup in large systems. We believe any meaningful review of the cost effectiveness and suitability of PACT/WAR technology must contain such an analysis in order to reach valid conclusions. Although the authors state that "insufficient data are available from the recently constructed full-size Kalamazoo DSE facility to determine the cost/benefit associated with the operation," the Kalamazoo DSE system has been operational since June. Ash removal and cost data are available and were simply not included because of a rush to meet an artificial deadline for this paper.

In summary, we support the objectives of this paper, but believe the data and their interpretation are erroneous. At the very least, additional work should be done to establish an acceptable analytical procedure for determining the carbon content of the regenerated stream from the WAR unit before any meaningful conclusions can be reached. At the most, EPA may want to retain a new contractor to re-evaluate all available PACT/WAR system data and gather additional information so that the paper's laudable objectives can be achieved. Although in the meantime we do not believe the paper can be the basis for any final Agency action, we do believe that we can work with EPA to address any existing questions the Agency may have.

Very truly yours,

ZIMPRO/PASSAVANT INC.

Alfred Slatin
President

AS/mrl
5477

cc Patrick Raher, Esq., Hogan & Hartson

APPENDIX B

FINAL COMMENTS FROM PAC PROCESS MANUFACTURER (ZIMPRO)

ZIMPRO
PASSAVANT

INNOVATIVE WASTE TREATMENT TECHNOLOGY

Zimpro systems
Passavant equipment
Hydro-Clear® filters
A member of The Ventures Group

May 23, 1989

Mr. James A. Heidman
Office of Research and Development
United States Environmental Protection Agency
Cincinnati, OH 45268

Dear Mr. Heidman:

In our previous comments on the technical paper entitled "Evaluation of Full Scale Activated Sludge Systems Utilizing Powdered Activated Carbon Addition with Wet Air Regeneration" by Deeny, Heidman, and Condren, we commented on (1) carbon usage, (2) cost effectiveness, and (3) ash accumulation. Those same comments also apply to this EPA report. In addition, the present comments are directed to the issues of (1) the effectiveness of the Differential Sedimentation and Elutriation (DSE) ash removal system, (2) "non-descript" volatile suspended materials in powdered activated carbon/wet air regeneration systems, and (3) treatment costs for facilities which use powdered activated carbon/wet air regeneration systems.

1. The effectiveness of the DSE ash removal system. A DSE ash removal system was installed at the Kalamazoo, Michigan wastewater treatment plant and became operational in June, 1988. The DSE system has been operated since start-up and has exceeded the design basis of pounds of ash removed per day (2 units each at 4000 lbs/day) and loss of volatile solids (less than 15 percent volatile solids in the dewatered ash). A compilation of data concerning ash removals is shown in Table 1. This data shows that on a monthly average, over the specified ten month period, 681,878 lbs of ash enter the Kalamazoo wastewater treatment plant and 743,998 lbs of ash were removed. Removal of ash is accomplished in both the primary and secondary (powdered activated carbon treatment, PACT™) steps. In the primary step, incinerator ash is the final form of removed ash (263,230 lbs/month average). In the secondary PACT™ system, the DSE system produces a dewatered ash cake at an average rate of 366,226 lbs/month. Ash is also removed from the treatment plant as suspended solids in the effluent (114,542 lbs/month average). The dewatered, filter press ash cake from the DSE system at Kalamazoo is very dry, >60 percent dry solids, and typically has a volatile content of less than 15 percent. The volatile portion of this material is comprised of carbon and water of hydration associated with the ash components, e.g. aluminum salts.

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The impact of removing this quantity of ash from the Kalamazoo secondary PACT system is shown in Figure 1, where the ash component of the mixed liquor suspended solids has been charted over the past year. When the DSE system was placed into operation in June of 1988, the percentage of ash in the mixed liquor had accumulated to approximately 63 percent of the suspended solids. After operating the DSE system for a ten month period, the ash content has been reduced to approximately 51 percent of the suspended solids. The overall concentration of suspended solids in the mixed liquor has also decreased from approximately 28,000 mg/l to approximately 22,000 mg/l, as shown in Figure 2.

All the costs for operation of the DSE ash removal system have not been fully assessed at this time. However, for the Kalamazoo treatment plant, the incremental cost for ash separation and carbon recovery definitely appears to be cost effective compared to the alternatives of ash removal by wasting carbon with ash.

2. Non-Descript Volatile Suspended Material. The authors of the present report conclude that the effluent from a Wet Air Regeneration (WAR) unit contains a "non-descript volatile suspended material". This material they claim is a "substantial fraction of material measured as biomass that is really just VSS which did not go into solution". If this material did persist in the quantities that the authors estimate, "five to six percent of the sum of the primary effluent volatile suspended solids plus new biomass growth", which is neither oxidized in the WAR unit or biodegraded in the PACT unit, then an accumulation of this volatile suspended solids would surely be evident. Inspection of Figure 2 does not indicate any long term accumulation of this non-descript volatile suspended material ("measured as biomass") as the authors claim. The authors used a data base from Kalamazoo during the time period of January through September, 1987 on which to base the alleged accumulation of non-descript volatile suspended solids. It appears that an increase in biomass was evident during this time frame. However, what the authors overlooked was the decrease in biomass concentration that occurred just subsequent to this time period. The long term (three year) trend appears to be a rather constant level of biomass with minor short term flucculations. It should be noted that Figure 3 also shows the accumulation of ash that occurred at the start-up of the PACT/WAR system in 1986 and the reduction of ash corresponding to the start-up of the DSE ash removal system in June, 1988.

3. Treatment Costs: Overall wastewater treatment costs for PACT™/WAR systems are available from Kalamazoo, East Burlington, and El Paso. At Kalamazoo, an industrial and municipal sewage receives separate primary treatment prior to mixing. The mixed sewage is then treated in a PACT system, which is operated in a nitrifying mode. The secondary PACT effluent receives tertiary treatment in a shallow bed, single media, sand filter prior to disinfection by chlorination and final discharge to the Kalamazoo River. The primary sludge solids at Kalamazoo are thermally conditioned, dewatered, and incinerated. The secondary sludge is processed through the WAR unit and the regenerated carbon is recycled to the PACT system. Ash, from the incinerator and the DSE system is disposed of in a landfill. The Kalamazoo treatment plant is designed for a flow of 53 million gallons per day (MGD). In 1986 the actual flow averaged 26 MGD. The total operating and maintenance costs in 1986 were $0.32 per thousand gallons of wastewater treated[1].

At East Burlington, a combined industrial and municipal sewage receives primary treatment, prior to secondary treatment in a nitrifying PACT system. The secondary effluent receives tertiary sand filtration, and chlorine disinfection before discharge. The primary sludge is aerobically digested, dewatered, and disposed of in a landfill. The secondary sludge is processed in a WAR unit and the regenerated carbon is recycled to the PACT system. A portion of the WAR effluent is coagulated, thickened and dewatered to control ash levels in the PACT system. The East Burlington wastewater treatment plant was designed for a flow of 12 MGD. In 1986 the average daily flow was 5.8 MGD. The total operating and maintenance costs in 1986 were $0.56 per thousand gallons treated[2].

The Fred Harvey Water Reclamation Plant in El Paso, Texas uses a multi-stage PACT system, along with the WAR system, for secondary treatment of their sewage. At this 10 MGD water reclamation and groundwater recharge facility, domestic sewage is treated by ten separate processes before the effluent is returned to the aquifer through a network of recharge wells. Since the wastewater treatment plant effluent is being added to a protected raw water supply, treatment to drinking water quality standards is required. The overall wastewater treatment scheme at El Paso consists of primary treatment followed by a two stage PACT system

for secondary treatment. Following secondary treatment, the effluent is further treated by high lime treatment to effect virus inactivation, removal of phosphorus, and removal of heavy metals. Following high lime treatment, the effluent undergoes recarbonation, utilizing carbon dioxide in a two stage system. The recarbonated effluent is then filtered in sand filters for reduction of turbidity. Final disinfection is accomplished by ozonation and chlorination and the disinfected product water is passed through granular activated carbon filters. The product water is stored in tankage while verification of the effluent quality is accomplished. After verification of the effluent quality is completed, the product water is reinjected into the aquifer.

The two stage PACT system at El Paso achieves a high removal of organic contaminants, complete nitrification, and denitrification of the wastewater.

The primary sludge is anaerobically digested and dried on drying beds. The secondary sludge is processed through a WAR unit and the regenerated carbon is returned to the PACT™ system. A portion of the secondary sludge is wasted to the anaerobic digesters to control the ash level in the PACT process.

The average daily flow through the El Paso plant during 1986 was 4.4 MGD. The operating and maintenance costs for 1986 were $1.55 per thousand gallons treated[3].

Considering the degree of wastewater treatment that is accomplished at these three treatment plants, using the PACT/WAR process, the overall treatment costs are not considerably different from the projected costs which were used in the cost effectiveness studies that were an integral part of the construction grants program.

These comments are submitted to the EPA to present an alternative viewpoint to the conclusions that were reached by the Agency and its Contractors. The cost information that is presented in these comments indicates that much data which was available to the investigators was either overlooked or was neglected in their findings. The overall treatment cost information is believed to be essential in the evaluation of the PACT™/WAR technology.

Zimpro/Passavant, Inc. reiterates its willingness to work with the EPA to achieve the stated objectives of this evaluation of the PACT™/WAR technology.

Very truly yours,

ZIMPRO/PASSAVANT INC.

Alfred Slatin

Alfred Slatin
President

References:

1. Orlin, K. Leon, "Wastewater Treatment in Kalamazoo", presented at the American Public Works Association Conference, Winnepeg, Canada, June 1987.

2. City of Burlington, East Burlington Wastewater Treatment Plant, Operations Report, 1986.

3. Daniel B. Knorr, et. al., "Wastewater Treatment and Groundwater Recharge: A Learning Experience at El Paso, TX", Proc. Water Reuse Symp., Vol. 4, 1988.

Table 1: ASH REMOVAL AT THE KALAMAZOO WWTP

	Lbs Ash In	Lbs Ash Out				Ml Ash* %
		Primary	DSE	Effluent	Total	
July, 1988	752,423	465,882	267,366	61,933	795,181	62.9
Aug. 1988	832,384	258,257	313,322	70,739	642,318	60.6
Sept. 1988	770,598	285,163	391,593	104,328	781,084	59.4
Oct. 1988	820,023	386,761	439,082	154,769	980,612	57.9
Nov. 1988	536,580	291,808	401,044	99,541	792,393	56.8
Dec. 1988	614,935	124,139	381,761	83,402	589,302	55.0
Jan. 1989	519,736	143,146	266,134	125,272	534,551	52.3
Feb. 1989	596,924	136,081	338,026	226,183	700,289	49.7
Mar. 1989	692,130	162,891	487,087	86,410	736,388	50.6
Apr. 1989	683,047	378,174	376,847	132,838	887,859	51.7
TOTAL	6,818,780	2,632,302	3,662,262	1,145,415	7,439,977	-
Monthly Average	681,878	263,230	366,226	114,542	743,998	-

* Seven Day Moving Average

Figure 1

MLSS Ash Concentration Trend at Kalamazoo

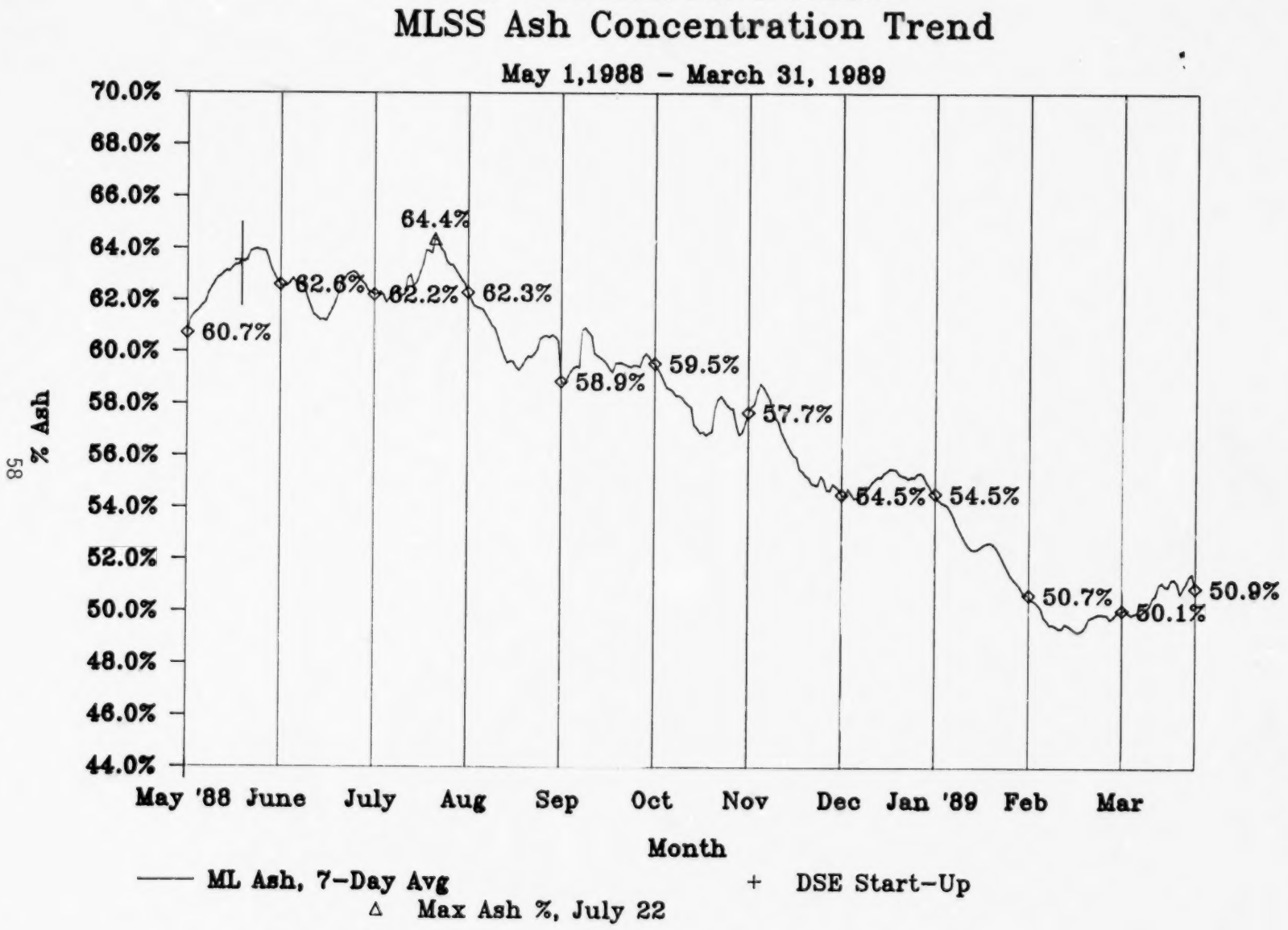
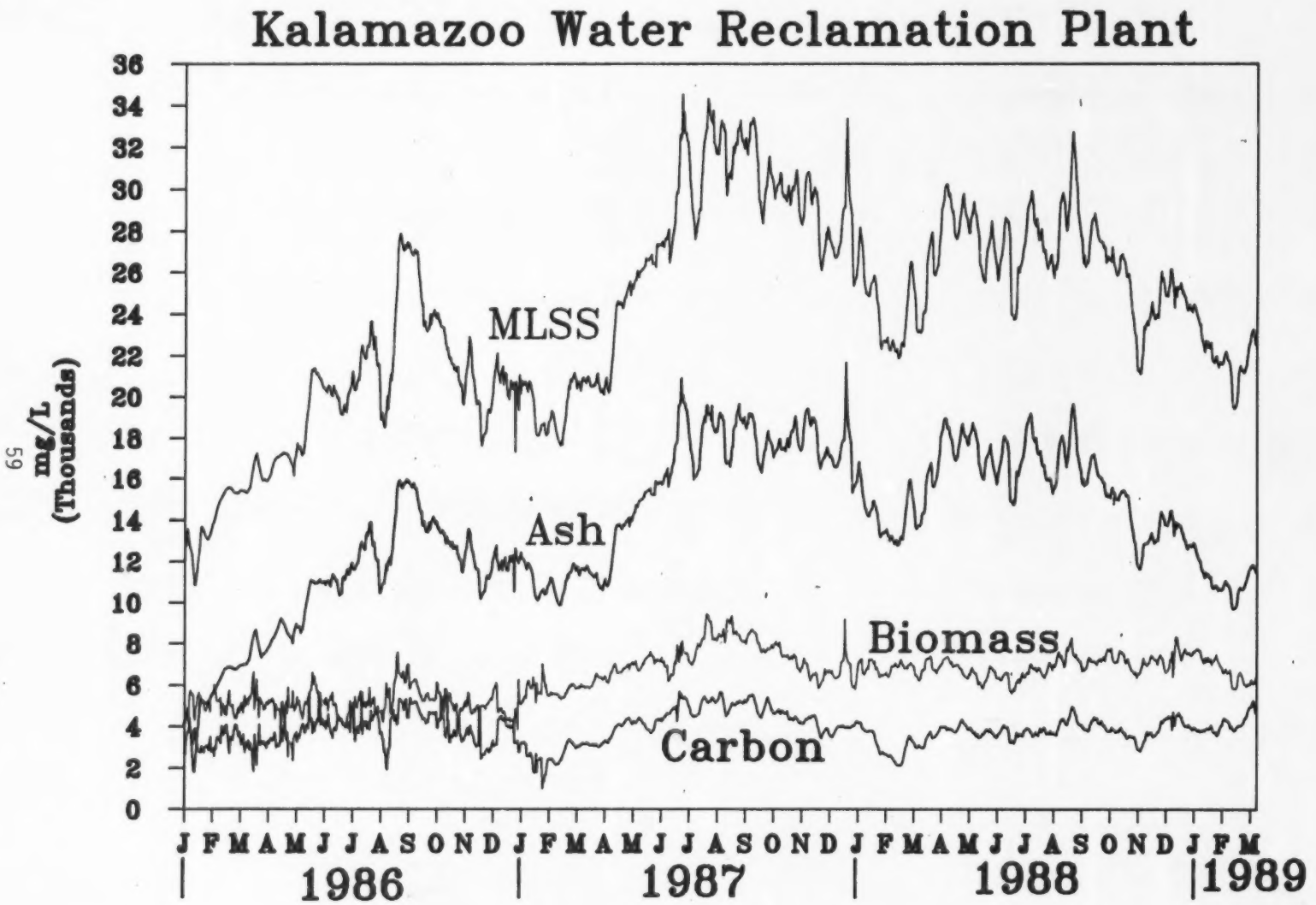


Figure 2

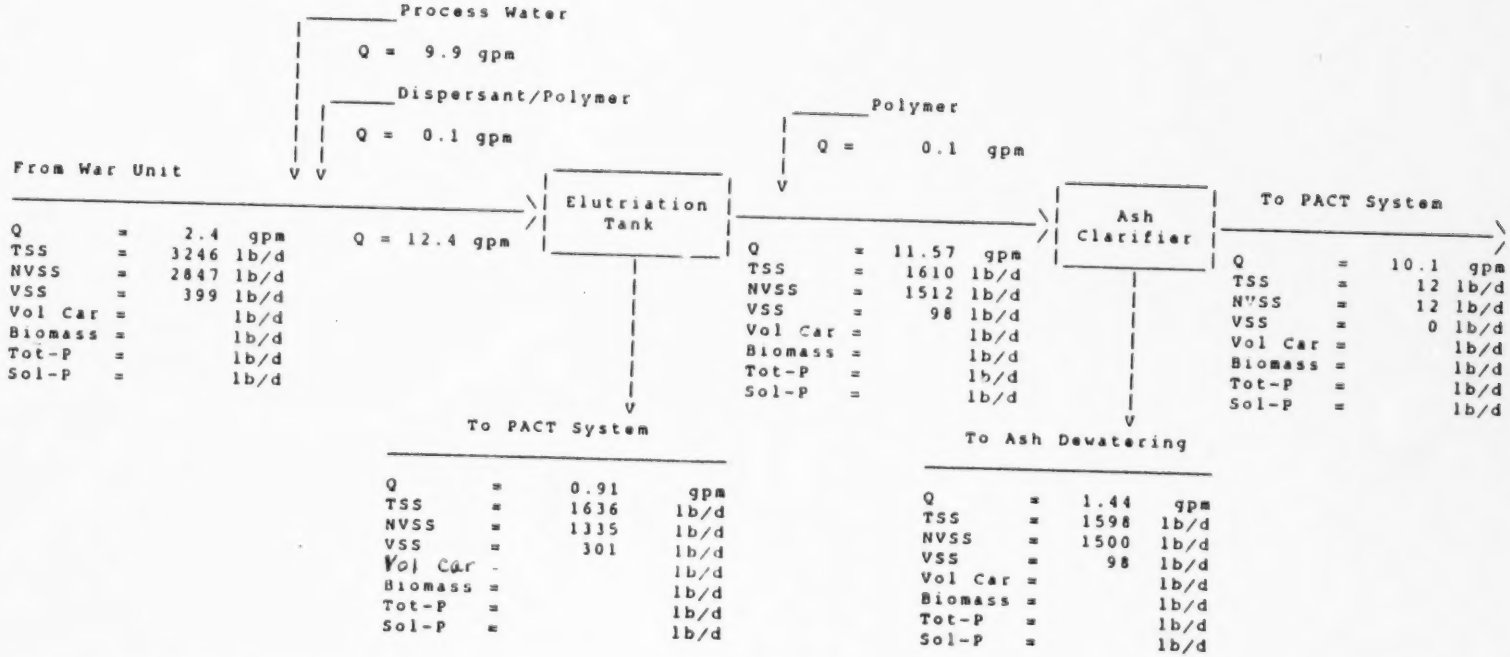
Components of the MLSS at Kalamazoo Long Term Trend Plot



APPENDIX C

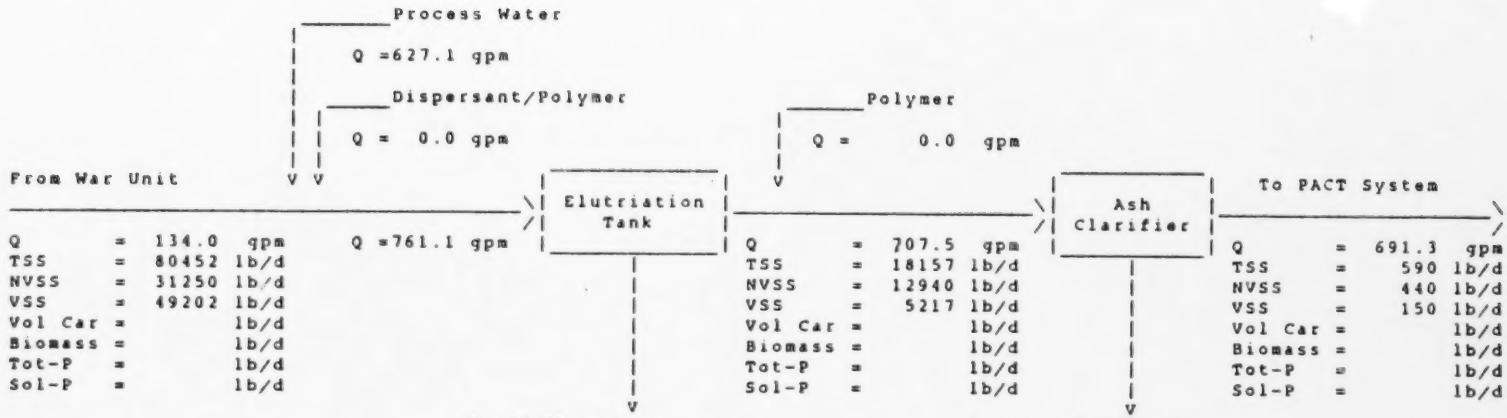
DSE PILOT STUDY

SUMMARY



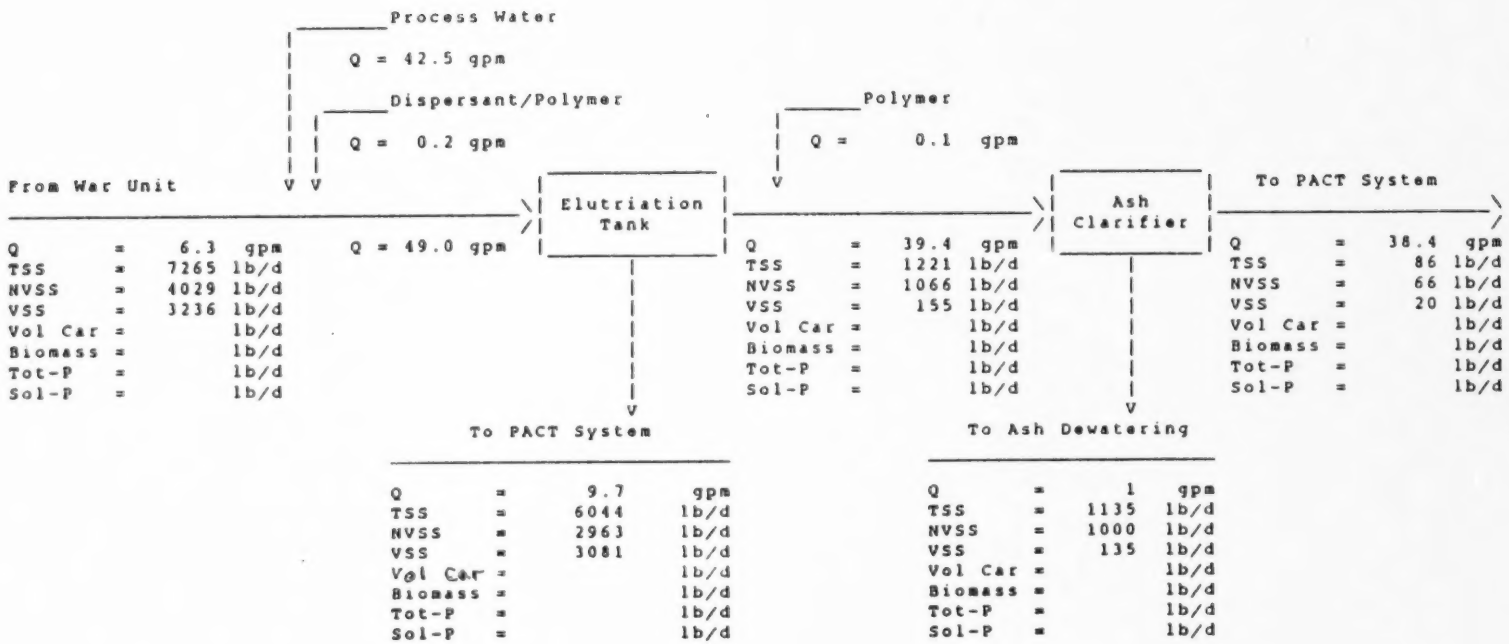
Five Day per Week Operation

Facility Location	Vernon, Connecticut			
Nominal WAR Capacity	1-50	gpm	Reported Ash Removal	52.7%
Virgin Carbon, % Ash	29.0	%	Reported VSS Recovery	75.4%
			Reported Vol Carbon Recovery	



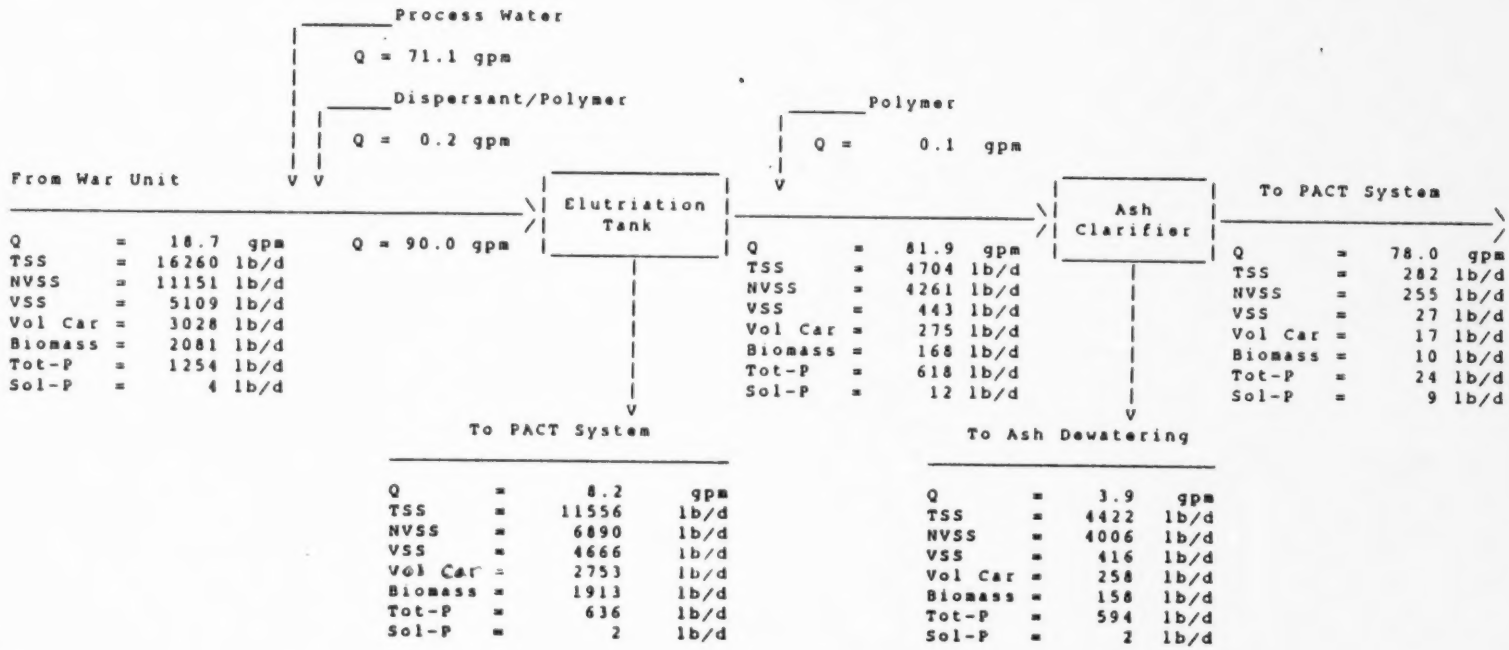
Continuous Operation

Facility Location	Sauget, Illinois	Reported Ash Removal	40.0%
Nominal WAR Cpacity	2-69 gpm	Reported VSS Recovery	89.7%
Virgin Carbon, % Ash	29.0 %	Reported Vol Carbon Recovery	



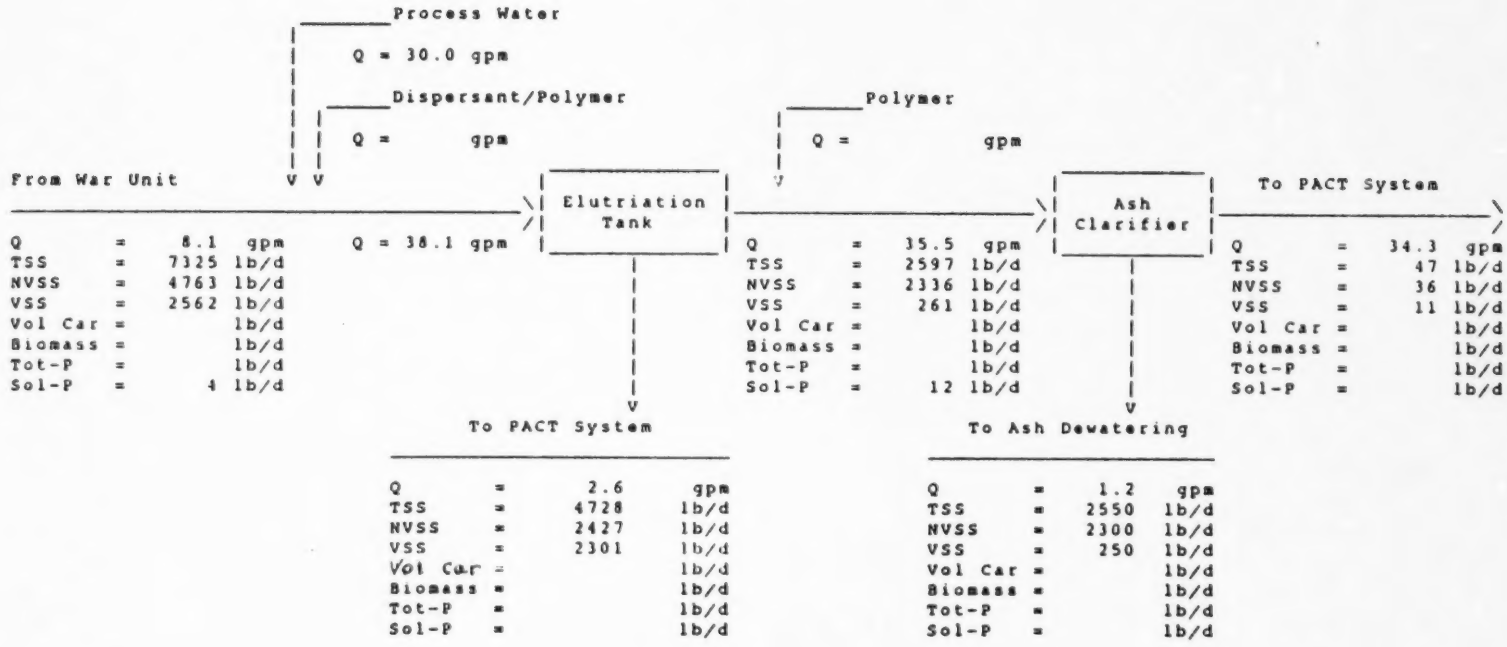
Five Day per Week Operation

Facility Location	El Paso, Texas	Reported Ash Removal	24.8%
Nominal WAR Capacity	1-58 gpm	Reported VSS Recovery	95.8%
Virgin Carbon, % Ash	29.0 %	Reported Vol Carbon Recovery	



Continuous Operation

Facility Location	Kalamazoo, Michigan	Reported Ash Removal	35.9%
Nominal WAR Capacity	4-110 gpm	Reported VSS Recovery	91.9%
Virgin Carbon, % Ash	29.0 %	Reported Vol Carbon Recovery	91.5%



Three Day per Week Operation

Facility Location	Bedford Heights, Ohio	Reported Ash Removal	48.3%
Nominal WAR Capacity	1-17 gpm	Reported VSS Recovery	90.2%
Virgin Carbon, % Ash	29.0 %	Reported Vol Carbon Recovery	

APPENDIX D

WET AIR REGENERATION
DATA SUMMARY

WAR MEASUREMENTS AT THE EAST BURLINGTON PLANT

DATE	CARBON FEED MG/L	BIOMASS FEED MG/L	REGEN CARBON MG/L	REGEN BIOMASS MG/L	CARBON LOST MG/L	BIOMASS LOST MG/L	CARBON REMOVED	BIOMASS REMAIN	FRACTION BIOMASS WAR EFF
1/87	16568	21900	8400	3180	8168	18720	0.492998	0.145205	0.274611
	12589	19771	11137	4003	1452	15768	0.115338	0.202468	0.264398
	14126	20914	9937		4189	20914	0.296545		
2/87	14168	22912	8737	3283	5431	19629	0.383328	0.143287	0.273128
	15726	20494	7516	2804	8210	17690	0.522065	0.136820	0.271705
	10821	18719	9832	4288	989	14431	0.091396	0.229072	0.303682
3/87	13074	27826	11853		1221	27826	0.093391		
	13495	23865	9095	2885	4400	20980	0.326046	0.120888	0.240818
	11347	22353	7621	2679	3726	19674	0.328368	0.119849	0.260097
	12526	22199	6421	4179	6105	18020	0.487386	0.188251	0.394245
4/87	9084	17546	5663	2330	3421	15216	0.376596	0.132793	0.291505
	8526	21774	6421	2499	2105	19275	0.246891	0.114769	0.280156
	11600	18600	6484	2216	5116	16384	0.441034	0.119139	0.254712
5/87	10295	18805	6758	2162	3537	16643	0.343564	0.114969	0.242376
	11032	19628	7389	1491	3643	18137	0.330221	0.075962	0.167905
	11495	20945	6884	1716	4611	19229	0.401130	0.081928	0.199534
	10611	18469	7305	2015	3306	16454	0.311563	0.109101	0.216201
6/87	11495	21165	7958	3182	3537	17983	0.307698	0.150342	0.285637
	15221	23159	7576		7645	23159	0.502266		
	19979	24921	8211	2969	11768	21952	0.589018	0.119136	0.265563
	20674	19246	15200	2660	5474	16586	0.264777	0.138210	0.148936
7/87	20232	21748	22800	1320	-2568	20428	-0.12692	0.060695	0.054726
	23326	20954	19621	3119	3705	17835	0.158835	0.148849	0.137159
	17505	38245	14463	4197	3042	34048	0.173778	0.109739	0.224919
	21011	22409	13832	3148	7179	19261	0.341678	0.140479	0.185394
8/87	24063	22537	17705	3475	6358	19062	0.264223	0.154190	0.164069
	24105	20455	20189	3031	3916	17424	0.162455	0.148178	0.130534
1/88	24295	20645	16605	3280	7690	17365	0.316526	0.158876	0.164948
	18358	24702	9095	1185	9263	23517	0.504575	0.047971	0.115272
2/88	19663	24277	16884	336	2779	23941	0.141331	0.013840	0.019512
	24868	25917	15937	823	8931	25094	0.359136	0.031755	0.049105
COUNT	31	31	31	28	31	31	31	28	28
AVG	15867.	22164.5	11081.	2659.10	4785.4	19762.74	0.307975	0.123456	0.210030

MT. HOLLY WAR DATA FOR 1987

DATE	FEED CARBON MG/L	FEED BIOMASS MG/L	WAR OUT CARBON MG/L	WAR OUT BIOMASS MG/L	CARBON LOSS MG/L	BIOMASS LOSS MG/L	CARBON REMOVED	BIOMASS REMAIN	BIOMASS IN WAR EFFLUENT
1/7	13137	19363	12084	1016	1053	18347	0.08015	0.05247	0.07756
1/12	15137	20863	9663	3137	5474	17726	0.36163	0.15036	0.24508
1/13	15389	21261	11347	2113	4042	19148	0.26265	0.09938	0.15698
1/16	15726	18024	11979	2281	3747	15743	0.23826	0.12655	0.15996
1/21	14547	15553	11010	1910	3537	13643	0.24314	0.12280	0.14783
1/28	14042	19908	7326	1324	6716	18584	0.47827	0.06650	0.15306
2/2	13600	21650	10674	2306	2926	19344	0.21514	0.10651	0.17766
2/3	14421	21779	4095	3965	10326	17814	0.71603	0.18205	0.49194
2/9	14547	19903	9179	1361	5368	18542	0.36901	0.06838	0.12913
2/11	14526	21674	7979	3421	6547	18253	0.45070	0.15783	0.30009
2/16	16463	23787	8421	2139	8042	21648	0.48848	0.08992	0.20256
2/18	16631	23219	8042	2198	8589	21021	0.51644	0.09466	0.21465
3/2	15053	26347	7684	2436	7369	23911	0.48953	0.09245	0.24071
3/8	18568	26532	6820	2040	11748	24492	0.63270	0.07688	0.23025
3/11	12400	21100	8274	2366	4126	18734	0.33274	0.11213	0.22237
3/23	7579	23771	5389	5291	2190	18480	0.28895	0.22258	0.49541
3/30	11495	17355	7768	2972	3727	14383	0.32422	0.17124	0.27672
4/1	7895	20555	7263	2517	632	18038	0.08005	0.12245	0.25736
4/3	8632	19368	7200	2360	1432	17008	0.16589	0.12185	0.24686
4/8	9221	21829	8989		232		0.02515		
4/13	12105	25645	9032		3073		0.25386		
4/15	15421	22779	8147	3233	7274	19546	0.47169	0.14192	0.28409
4/20	12568	24132	6758	1742	5810	22390	0.46228	0.07218	0.20494
4/22	10358	21092	7853	2267	2505	18825	0.24184	0.10748	0.22401
4/27	16042	12858	9221	2379	6821	10479	0.42519	0.18502	0.20509
4/29	15431	20719	9474	1493	5957	19226	0.38604	0.07205	0.13614
5/1	15074	21326	10105		4969		0.32964		
5/18	14610	19090	7495	1825	7115	17265	0.48699	0.09559	0.19582
5/20	13263	15437	10316	984	2947	14453	0.22219	0.06374	0.08708
5/22	14105	18495	6737	3603	7368	14892	0.52236	0.19480	0.34845
5/28	16716	15934	12737		3979		0.23803		
6/3	16042	5758	10400	2320	5642	3438	0.35170	0.40291	0.18239
6/4	20400	18700	15410	510	4990	18190	0.24460	0.02727	0.03204
6/10	20716	20484	11558	2162	9158	18322	0.44207	0.10554	0.15758
6/15	23453	21597	16821	1319	6632	20278	0.28277	0.06107	0.07271
6/17	17010	12090	12147	2653	4863	9437	0.28589	0.21943	0.17926
6/18	20442	17008	16505	3635	3937	13373	0.19259	0.21372	0.18049
6/23	18631	18419	14379	4481	4252	13938	0.22822	0.24328	0.23759
6/25	21621	17449	15705	5395	5916	12054	0.27362	0.30918	0.25569
6/29	20021	17529	14253	3347	5768	14182	0.28809	0.19094	0.19017
7/1	19516	13984	12442	4338	7074	9646	0.36247	0.31021	0.25852
7/6	22210	20940	15558	4002	6652	16938	0.29950	0.19111	0.20460
7/8	19979	12621	14505	3075	5474	9546	0.27398	0.24364	0.17491
7/13	17726	16874	16758	1842	968	15032	0.05460	0.10916	0.09903
7/15	16800	17500	11937	3823	4863	13677	0.28946	0.21845	0.24258
7/22	19747	14453	12547	2753	7200	11700	0.36461	0.19047	0.17993
7/27	14316	13734	10358	4782	3958	8952	0.27647	0.34818	0.31585
7/29	15831	9969	14463	937	1368	9032	0.08641	0.09399	0.06084
COUNT	48	48	48	44	48	44	48	44	44.00000
AVERAGE	15607.	18967.8	10516.81	2637.568	5090.75	16128.86	0.32076	0.15110	0.20764

NITRIC ACID MEASUREMENTS ACROSS WAR AT KALAMAZOO, MI

	MEASURED CARBON FEED	MEASURED BIOMASS FEED	UNIT REGEN	REGEN CARBON	REGEN BIOMASS	CARBON LOSS	BIOMASS LOSS	CARBON	BIOMASS	BIOMASS IN WAR EFFLUENT
2/3	13400		1		3340					
2/7	12900	26000	1	8000	4120	4900	21880	0.37984	0.15846	0.339933
2/7	12900	26000	2	7100	4260	5800	21740	0.44961	0.16384	0.375
2/10	12200	28150	1	6030	4950	6170	23200	0.50573	0.17584	0.450819
2/10	12200	28150	2	8790	5190	3410	22960	0.27950	0.18436	0.371244
2/14	13500	24200	1	7920	4430	5580	19770	0.41333	0.18305	0.358704
2/14	13500	24200	2	9420	5660	4080	18540	0.30222	0.23388	0.375331
2/17	13300	21900	1	8880	940	4420	20960	0.33233	0.04292	0.095723
2/17	13300	21900	2	6170	4890	7130	17010	0.53609	0.22328	0.442133
2/21	14200	25600	2	6030	3690	8170	21910	0.57535	0.14414	0.379629
2/24	14400	29650	2	8440	6420	5960	23230	0.41388	0.21652	0.432032
2/24	14400	29650	4		3960		25690		0.13355	
2/28	19000		4	14400	5140	4600		0.24210		0.263050
3/2	14500	32600	2	11400	12560	3100	20040	0.21379	0.38527	0.524207
3/2	14500	32600	4	11400	7780	3100	24820	0.21379	0.23865	0.405630
3/6	19900	33600	3	14200	5260	5700	28340	0.28643	0.15654	0.270298
3/6	19900	33600	4	9810	4690	10090	28910	0.50703	0.13958	0.323448
3/9	16800	34300	3	8320	7060	8480	27240	0.50476	0.20583	0.459037
3/9	16800	34300	4	7930	5730	8870	28570	0.52797	0.16705	0.419472
3/16	18600	38050	1	6250	3130	12350	34920	0.66397	0.08226	0.333688
3/20	19200	50140	3	7760	7140	11440	43000	0.59583	0.14240	0.479194
3/24	14800	28350	3	6790	4080	8010	24270	0.54121	0.14391	0.375344
3/24	14800	28350	4	6510	6800	8290	21550	0.56013	0.23985	0.510894
3/27	14500	34180	3	14900	5360	-400	28820	-0.0275	0.15681	0.264560
3/30	18100	35250	1	11900	5360	6200	29890	0.34254	0.15205	0.310544
3/30	18100	35250	3	11900	5200	6200	30050	0.34254	0.14751	0.304093
4/3	19600	35400	1	6580	4280	13020	31120	0.66428	0.12090	0.394106
4/6	21200	31650	1	14600	4620	6600	27030	0.31132	0.14597	0.240374
4/6	21200	31650	4	9380	5140	11820	26510	0.55754	0.16240	0.353994
4/13	20100	29100	1	7160	1620	12940	27480	0.64378	0.05567	0.184510
4/13	20100	29100	4	13900	5820	6200	23280	0.30845	0.2	0.295131
4/17	16400	31150	1	7960	3300	8440	27850	0.51463	0.10593	0.293072
4/17	16400	31150	4	7540	4440	8860	26710	0.54024	0.14253	0.370617
4/20	23300	29100	4	19100	3880	4200	25220	0.18025	0.13333	0.168842
4/24	31700	24600	3	21600	4260	10100	20340	0.31861	0.17317	0.164733
4/28	20100	29090	3		3010		26080		0.10347	
5/1	24000	39650	3	17600	7240	6400	32410	0.26666	0.18259	0.291465
5/1	24000	39650	4	14300	8220	9700	31430	0.40416	0.20731	0.365008
5/4	24000	34750	3	16600	6220	7400	28530	0.30833	0.17899	0.272567
5/4	24000	34750	4	15800	4900	8200	29850	0.34166	0.14100	0.236714
5/8	23300	18650	3	19300	6660	4000	11990	0.17167	0.35710	0.256548
5/8	23300	18650	4	18000	8180	5300	10470	0.22746	0.43860	0.312452
5/11	24200	29350	4	19100	5020	5100	24330	0.21074	0.17103	0.208126
5/15	25400	35800	1	7010	2690	18390	33110	0.72401	0.07513	0.277319
5/15	25400	35800	4	9130	3410	16270	32390	0.64055	0.09525	0.271929
5/18	23900	25250	1	11800	3660	12100	21590	0.50627	0.14495	0.236739
5/18	23900	25250	4	14700	4120	9200	21130	0.38493	0.16316	0.218916
5/22	17300	23900	1	15500	4720	1800	19180	0.10404	0.19748	0.233432
5/25	19600	29050	1	7060	3560	12540	25490	0.63979	0.12254	0.335216
COUNT	49	47		46	49	46	47	46	47	46
AVG	18614.28	30392.76		11173	5022.653	7613.6	25336.80	0.40591	0.17098	0.322735

APPENDIX E

ANALYSIS OF PAC LOSS IN THE BACK RIVER PILOT STUDY (25)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
WATER ENGINEERING RESEARCH LABORATORY
CINCINNATI, OHIO 45268

DATE: June 14, 1988

SUBJECT: Analysis of Carbon Balance Data for the Back River Pilot Study

FROM: James A. Heidman JAH

TO: RECORD

A review of the report "Pilot Activated Sludge and Powdered Carbon Enhanced Activated Sludge Study at Baltimore Maryland's Back River WWTP", prepared by Zimpro, Inc. provides the following information about the carbon balances associated with wet air regeneration.

Powdered activated carbon was added to the system on October 1 and the pilot program was concluded on November 20. During the last three weeks of the study, filter backwash was not returned to the system. Also on several occasions it was necessary to dispose of some of the wasted solids rather than regenerate them due to capacity limitations in the regeneration unit. The conclusions to the report state (pg. 6), "the wet air regeneration unit handled more than 1925 pounds of spent carbon solids from the PACT process with carbon recovery efficiencies in excess of 95% for the study."

According to the information on pg. 108, "performing a solids balance around the regeneration unit is quite difficult due to the imprecise nature of the carbon/biomass analysis. The solids balance around the unit indicated that 685.2 pounds of spent volatile carbon were fed to the unit and 861.3 pounds were present in the regenerated carbon stream. The vagaries of sampling and the variability in the analysis due to acid hydrolysis account for the discrepancy."

A carbon mass balance was performed over the entire period with the claim that the balance is far more precise than the nitric acid procedure in monitoring carbon losses. "If all losses were to be considered only due to oxidation, the loss would be 4.6 percent of all carbon applied."

Selected field data reported for the spent and regenerated solids streams are attached. There is no analysis of carbon by the nitric acid procedure given for the regenerated stream. The regeneration unit was operated for 509 hours and the unit operated at an average of 8.06 gph giving a total regeneration flow of 4102.5 gallons. The regeneration VSS values for 10/4 and 10/5 are obviously in error (see attached) and the mean of the

other 44 measurements is 25066 mg/l corresponding to regeneration VSS of 858 lb. Hence the above statement which states that 861.3 pounds of volatile carbon were present in the regenerated stream really refers to VSS. The average of the 45 measures for spent carbon is 20999.4 mg/l which correspond to 718.7 lb of carbon in the spent waste stream. If the data for 10/4 and 10/5 are also neglected, the mean feed carbon is 700.1 lb, which is close to the reported value of 685.2 lb.

The carbon balance, which is claimed to be far more precise than the nitric acid procedure, in fact has to rely on the nitric acid procedure to attempt to quantify all of the carbon leaving in the various streams. Furthermore this procedure relies on one sample on 11/20 to compare the theoretical balance with the actual balance at that time. The rationale whereby directly measuring the carbon by the nitric acid procedure across the WAR unit a total of 44 to 45 times is unacceptable but relying on the same nitric acid procedure plus VSS for blowdown carbon for all of the other waste streams is "better" and comparing this to a single measurement at the end of the study escapes this reviewer.

The discrepancy in the carbon balance presented in Table 5-4 was 59.1 lbs. This value was divided by 1292.6 lb of "Total Vol. Carbon Fed" to arrive at the 4.6% value for the losses in WAR. The average VSS fed to WAR in the attached summary was 37093 mg/l (n = 44) and this corresponds to 1269.8 lb. It is not clear why the vagaries of sampling which made it unacceptable to use the nitric acid determined carbon values in this stream (685.2 lbs) do not seem to pose any problem with the VSS measurements in this same stream. Even more astounding is the supposition that the percentage of carbon losses can be determined by dividing by the combined sum of the biomass carbon and carbon volatile solids.

The TSS fed to the WAR unit averaged (19115 mg/l ash + 37093 mg/l VSS) or 1924 lbs. This value is apparently the basis for the assertion that over 1925 lbs of "spent carbon solids" were handled by wet air regeneration.

An ash balance was performed on an activated sludge system run before the carbon addition was initiated and also on the PACT system. The results were presented in Table 5-5 and showed an excellent ash balance for the activated sludge but an excess of 1551 mg/l of ash out of a concentration of 10373 for the PACT system. It was indicated that the negative value for the PACT ash is due to the inaccuracy of the carbon/biomass test. The ash associated with the carbon was indicated to be 4410 lb. Reducing the carbon concentration by 35.2 % would result in an ash balance. Furthermore since an overmeasurement of carbon results in an undermeasurement in "biomass" the increased ash mass associated with more biomass means that the carbon concentration would need to be reduced even further to achieve an ash balance.

The initial volatile carbon charge was 131.6 lbs, makeup volatile carbon was 126.3 lbs, and discarded carbon replacement was an additional 174.1 lbs volatile carbon. The total of 432.0 lbs volatile carbon is not subject to measurement errors associated with the nitric acid procedure. In seven weeks, the replacement virgin carbon addition was 2.28 times the initial carbon charge. Based upon the ash balances, the actual carbon level in the waste streams and in the aerator at the end of the study was probably about 65 % (or less) of the measured nitric acid values meaning that all of the volatile carbon losses and remaining carbon reported in Table 5-4 should be reduced from 372.9 lb to 242.4 lb. This would make the carbon loss to WAR equal to 189.6 lb (432 - 242.4). Furthermore, the nitric acid measured stream to WAR should be reduced to (685.2 * .65) or 445.4 lb. This means that of the 445.4 lb of volatile carbon solids fed to WAR, 189.6 lb or 42.6% were lost in regeneration.

DATA FROM THE BACK RIVER PILOT PLANT STUDIES

DATE	SPENT BIOMASS	SPENT CARBON	SPENT VSS	REGEN SS	REGEN ASH	REGEN VSS
10/2						
3				29270	8330	20940
4		34221		129570	40340	89230
5	2618	31242	33860	116700	31460	85240
6	1091	24989	26080	20700	6640	14060
7	2897	23263	26160	53120	15120	38000
8	3759	22421	26180			
9				52060	16580	35480
10	7406	41894	49300	33140	9790	23350
11	9110	26860	35970	42100	14410	27690
12	1000	33010	34010	33760	12580	21180
13	8010	19460	27470	32580	12270	20310
14	4900	37100	42000	51050	18940	32110
15	11490	34270	45760	52000	19420	32580
16	10690	32690	43380	44890	18880	26010
17	3740	30060	33800	48100	18870	29230
18	14810	29070	43880	49570	20580	28990
19	19120	24420	43540	50400	20600	29800
20	15040	35200	50240	53410	22400	31010
21	14280	31520	45800	61630	25070	36560
22	15850	32090	47940	43810	18960	24850
23	21150	24050	45200	57210	25600	31610
24				45020	20260	24760
25	24900	14860	39760	43570	20700	22870
26	28020	14200	42220	56450	27060	29390
27	25430	12680	38110	51820	24660	27160
28	28750	14160	42910	65710	36670	29040
29	23610	13590	37200	57290	25700	31590
30	22700	13720	36420	66100	27150	38950
31	23360	16700	40060	60060	26340	33720
11/1	21550	15410	36960	65300	26340	38960
2	17460	15290	32750	46080	21180	24900
3	23390	14990	38380	50580	22000	28580
4	20190	12270	32460	46790	22340	24450
5	20350	14210	34560	42580	19370	23210
6	20900	13500	34400	35160	17500	17660
7	20820	12460	33280	41600	20970	20630
8	23716	12724	36440	34210	18610	15600
9	19832	17248	37080	35220	19890	15330
10	21250	16650	37900	27220	17310	9910
11	18168	15390	33558	42130	21710	20420
12	18737	11940	30677	36820	18820	18000
13	20674	15063	35737	39840	21270	18570
14	18100	12240	30340	40070	21040	19030
15	21380	14780	36160	36910	19650	17260
16	18960	12950	31910	33870	18360	15510
17	17700	14100	31800	37690	20310	17380
18	17160	16520	33680	37990	21730	16260
19	17290	19500	36790			
20						
COUNT	44	45	44	46	46	46
AVERAGE	16394.5	20999.44	37093.45	48503.26	20734.34	27768.91